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SURVEYING.

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LAND AND MARINE SURVEYING

IN REFERENCE TO THE PREPARATION OF PLANS FOR

ROADS AND RAILWAYS;
CANALS, RIVERS, TOWNS' WATER SUPPLIES;
DOCKS AND HARBOURS;

WITH

DESCRIPTION AND USE OF SURVEYING INSTRUMENTS.

BY

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AUTHOR OF 'THE ENGINEER'S, MINING SURVEYOR'S, AND CONTRACTOR'S FIELD-BOOK,'
'EXAMPLES OF BRIDGE AND VIADUCT CONSTRUCTION OF MASONRY,
TIMBER, AND IRON,' ETC. ETC.

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PREFACE.

EXPERIENCE has demonstrated, on more than one occasion, that knowledge of the technical details of Surveying is often deficient amongst junior practitioners, either because they have not had sufficient practice, or received from their seniors those friendly hints by which much of the knowledge acquired during many years of experience may often be imparted in a few words. This has led the Author of 'Land and Marine Surveying' to treat very fully, in the first chapters, of a number of details, on the understanding of which, though very simple in themselves, a combined accuracy and rapidity of operation mainly depend: these have been explained almost in the colloquial language in which a surveyor would address his pupils and assistants in the field, and the more fully that the combination of accurate and quick work is indispensable to secure practice. The Author has next proceeded to elucidate, in the same manner, the subject of making a survey without any other instrument than a chain; and this has been done in a series of examples, commencing with a single field, and gradually increasing in size and importance, up to large estates, and plans for engineering works. These preliminaries being made clear, even to those who are entirely deficient of actual practice, the Author proceeds to explain the construction, adjustment, and use of the principal surveying instruments; and as some knowledge of the *application* of Trigonometry is almost indispensable to a sound understanding of the full value of these instruments in the field, he has explained this application before proceeding with the more important branches of Surveying. It is only after the elucidation and discussion of all these matters, that he proceeds with similar practical details on the subject of those Road, Railway, Harbour, and other Surveys, which the young practitioner generally hopes to obtain the management of in the course of his future career.

LONDON: *March* 1868.

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LAND AND MARINE SURVEYING.

CHAPTER I.

ELEMENTARY.

CHAINS AND CHAINING; GUNTER'S CHAIN, THE 100 FEET CHAIN, AND THE DÉCAMÈTRE CHAIN; ARROWS; POLES AND RANGING RODS; PRICKING OR BONING OUT CHAIN LINES — OFFSETS — STATIONS — THE FIELD BOOK; SYSTEMATIC METHOD OF KEEPING THE FIELD BOOK.

THIS CHAPTER is written for those who are supposed to have had no practice whatever in Surveying, and, indeed, to know nothing whatever on the subject; numerous technical details are given, which, therefore, to be of any service, must be of a purely elementary character: the reader will be able to determine for himself how far it will be necessary for him to read the first few following pages; or whether he may *skip* them, and go on to other matter.

CHAINS AND CHAINING.

Chains.—There are two chains used by the land surveyor, besides the décamètre chain—*Gunter's* chain, and the 100 feet chain: the first, which is quite peculiar to this country, is 66 feet in length, but divided into 100 *links*, each of which measures, from centre to centre, 7·92 inches, every ten links being denoted by particular brass marks or 'fingers.' Where the only object of a survey is to prepare a plan of an estate, and take out the quantities of land in acres, roods, and perches, Gunter's chain is the most convenient.

The 100 *feet chain* is, as its name proclaims, 100 feet long; it is divided into 100 links, each of which of course measures 1 foot from centre to centre; every ten links is marked as in the former chain. This chain has gradually been growing in favour with the English engineering surveyor, and is used almost exclusively for work done abroad, unless by some legal enactment we are obliged to make use of metric measurements, in which case we employ the décamètre chain, which is 32·8 feet, or 10 mètres long.

The Décamètre chain is also divided into 100 links, each of which measures a décimètre, equal to 0·328 of an English foot. The very short length of this chain is somewhat against it, and, to overcome this objection, two décamètre chains are very commonly fastened together; sometimes a double décamètre chain is used, which is 65·6 feet long; this also may be divided into 100 links of 0·656 length each from centre to centre.

Where it is necessary to make use of the décamètre chain, and there is none ready at hand, the Gunter's chain is sometimes made use of, each link nearly corresponding to the double décamètre, and as its whole length is only about 0·4 of a foot longer than the double décamètre chain, it is not very troublesome to make a corresponding allowance in the field work or in the plotting, at every five or ten chains; it is, at the least, a very useful *makeshift*, and as such has often been had recourse to. Where a *double* décamètre chain is thus employed, a corresponding scale must of course be made use of.

The advantages of a long chain over a short one are evident enough, inasmuch as the measure being longer, we have only to apply it fewer times in ascertaining the length of a line, than we must do with a shorter measure, thus avoiding so many chances of error. Thus, if we could measure a mile with a one mile measure, we should only have one chance of error; but if we measure the mile with the 66 feet chain, we have to apply the measure eighty times, giving eighty chances of error instead of one; and if we use the 100 feet chain, we shall only have to apply it 52·80 times, giving nearly 50 per cent. less chances of error than in using the Gunter's chain. Moreover, a considerable amount of time is saved in fixing the arrows in the ground, as in the one case we have only 52·8 instead of eighty to measure a mile.

Again, we may observe that the only advantage of the Gunter's chain is the ready means of ascertaining acreage, for which it was originally intended, but it is quite inappropriate for engineering purposes, inasmuch as to make use of links of 7·92 inches either for measuring or setting out any works, we must reduce feet or yards into the lengths of such links. We have known experienced surveyors use a double Gunter's chain, that is 132 feet long; in wet weather it is heavy work to drag it.

We believe that the retention of the Gunter's chain for engineering purposes is due principally to the obstructive standing orders, but as we have not these to deal with out of this country, the 100 feet chain is used abroad more than any other, unless, indeed, as we have already observed, we have to make use of metrical measurements.

Arrows.—Each chain is accompanied by ten arrows; these are used to mark on each line chained the exact point, as regards length and direction, where each chain ends, and also the number of chains laid out. The arrows are made of stout iron wire, pointed at one end, and with a ring at the other, so that the whole ten may be conveniently carried on one finger. It will be found a good plan to sew a bit of red cloth or bunting to the ring of each arrow, as this not only makes the arrows much more readily visible in chaining through grass or other vegetation, but also in case of one being accidentally dropped about the ground, the bit of red colour makes it much more easily found.

Poles and Ranging-Rods.—The surveyor should be supplied with a few poles and ranging-rods; the distinction between the two is, that the first are generally much longer and stouter than the latter. We use poles in general surveying, ranging-rods being more generally employed in setting out lines. The few poles we use in surveying are very easily procured, being made of red pine, about 15 feet long, 2 inches thick at bottom, and ¾ inch thick at top, with the edges chamfered off for about 5 feet from the bottom. Every pole should be shod with a pointed iron shoe. Some surveyors have their poles rounded from top to bottom and painted white; the paint is an improvement, as it makes the pole last longer, but we hardly consider the expense necessary, for it is the fate of surveying poles to be constantly lost, broken, or left on the ground, when a survey is completed, for it is hardly considered worth while to send a man, perhaps half a dozen miles, to pick up a pole, left behind on the work. It is not indeed an uncommon thing to dispense with poles almost entirely, and to cut out of a copse or hedge a few of the tallest convenient sticks to be come at. We do not recommend this plan as one to be generally adopted, as it often occasions unpleasant quarrels with farmers.

We prefer purchasing a bundle of laths, of which the chainman can, without any inconvenience, carry out a dozen or so in the morning when going to work; being white from top to bottom, they are seen at a considerable distance, and are besides not apt to be mistaken for sticks often set up by farmer's men for their own work.

Abroad, certainly, a different course is pursued; poles are often considered an encumbrance; many surveyors do not hesitate at cutting down young trees, and turning them into poles.

This is often done before the owner's face, and without so much as asking his leave. We recommend a little consideration on the subject, as a great deal of illwill is often occasioned by these practices among the people dwelling along the line of works; this might be avoided by paying a few pence for the sticks required. Besides, much inconvenience is often occasioned, for we often find that our poles are pulled up and stations obliterated at the first convenient opportunity.

The young beginner should never forget that it is an important professional duty towards the undertaking with which he may be connected, to do all in his power to secure the utmost possible goodwill amongst the population in the district which the works may interfere with. A favourable prestige is often won by the observance of common civility only.

Ranging rods are shorter and slighter than surveying poles, and we never wish them to be more than about five or six feet long, about one inch thick at bottom, and about half an inch at top; they should be painted red and white, in foot lengths, from top to bottom. The advantage of these colours is, that it makes them more conspicuous than they would otherwise be, and that portions of them are often perceptible through the foliage of a hedge.

We do not often make use of them in surveying, but they are undoubtedly useful in setting out a line where the vegetation is of any height. Surveying poles, and ranging rods also, when used for surveying purposes, should have a flag of red and white bunting fastened on at top. This flag should be well secured to the pole; it should be about nine inches wide and fifteen inches long. We have already observed that, instead of making our poles round, we merely chamfer off the edges, and we consider this gives a man a better grip of the pole when driving it into the ground.

In a country where the vegetation is tall, as, for instance, hop grounds, vineyards, fig gardens, orange groves, or where there is a good deal of copse, we advise the surveyor to have his surveying poles not less than twenty feet high, if he can procure the stuff to make them with, and as we always have ours tapering from two inches at bottom to three-quarters at top, they are by no means heavy to carry about.

Having now said so much about poles, which sometimes we cannot do without, we must also observe that the constant use of them would often involve great loss of time, as, for instance, sending on a man half a mile or a mile, and often more, when there may be a tree, or chimney, or other conspicuous object on the ground which may answer the same purpose. Indeed, it is often worth while to make a slight alteration in the proposed direction of a surveying line, to avoid such loss of time; for not only the man may have to be sent on, merely for setting up a pole, but the surveyor himself would have to wait until the pole is set up. It is of no slight importance for the young surveyor to accustom himself as much as possible to do with only a few poles, and to learn how to set out his lines so as to take advantage of objects already on the ground; a poplar or fir, or even the black or white stem of a tree, a chimney or window in a house or cottage, the centre of a gate on high ground—any such objects will answer the purpose, with the further advantage that they are not readily removable, and may be found at any future time. For short distances we have even made use of a flower or conspicuous plant in a hedge. At the same time, however, it must be very distinctly understood, that it is indispensably necessary that the object be very conspicuous, and that another may not be mistaken for it, particularly as the chaining proceeds. For instance, we may suppose a line started at the foot of a hill, and sighted on a chimney in the distance; on reaching higher ground, two or three more may come in sight in close proximity to that selected, and although that selected will be higher than the others, care must be taken that no mistake is made, as a crooked line instead of a straight one would be the result.

Whites.—The use of poles may often be avoided by using whites; these consist of a few pieces of white paper stuck in the clefts cut in slight sticks cut from a hedge—about two or three feet long is quite sufficient. They are very convenient in setting out lines, where the fences are numerous or high, when vision of far objects is constantly obstructed as the chaining proceeds. Favourable positions, such as high ground, should be selected for setting out these whites; on coming to such a spot, the surveyor should send a man forward with a few whites, with instructions as to the fields where these are to be set up. The surveyor remains on the high ground, taking care that he is exactly on the line, and as the man reaches the various spots where the whites are to be set up, the surveyor makes signals by holding up his right or left hand, which guide the man in setting up the white; when it is exactly on the line, the surveyor holds up both hands together, and then drops both, suddenly, which is the signal that the white is to be there driven into the ground. The man then goes on into the next field chosen, perhaps two or three fields off, and the same operation is repeated. This is called *pricking or boning out.*

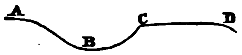
Whites are also very useful in sighting a line through a copse, either forwards or backwards. For instance, suppose that a line has already been chained forwards some eight or ten chains, and that we come to a copse through which the line has to be continued. Set up a pole at the beginning and ending of the part of the line already chained; or if we see that we shall shortly lose sight of the backward pole, then set up two or three whites, exactly on the line, and about a chain or two apart, so that we shall see them on getting some little way into the copse; then commence setting up whites, only a few yards apart, and exactly in line with those left behind; the more numerously they are set up the better, so that as we advance into the copse, we shall have at least three to guide us in setting up the next. By these means, and using a little care, we have often set out a line through a wood for fifteen and twenty chains, so as to be able to continue the chaining.

It is always well, under such circumstances, to select if possible some tree on the other side of the copse, under which we may see that the line will come out. We may do this before commencing the pricking out, and if we find at the end that the chain actually comes out under this tree, we may conclude that all is well. On coming to the other side of the copse, the line should be continued for some length, to give us the means of tying up the work ahead to the back-work. In these matters it is not always what we should like to do, but what we can do under the circumstances; and the sooner the young surveyor acquires the habit of doing these things under difficulties, the better for his practice. It will of course be understood that we are not now referring to an actual working survey—in which case we should have power to cut a road right through the wood, without any further trouble; we refer to a preliminary or parliamentary survey, where, in the first place, we have no right to cut, where perhaps our surveying is barely tolerated, to say nothing of the loss of time which would be incurred in cutting a path.

Where there is no tree or other object on the other side of the copse or wood, we have often sent two or three poles forward, with instructions that they should be tied together, and set up according to instructions, given by the voice instead of by signal, some three or four men being stationed at short intervals apart; signals may thus be carried forward from the surveyor at one end of the line to the man at the farther end. We have known this work carried on at night by means of lanterns, and although not the most pleasant it is perhaps the easiest and surest way of all.

Setting out Lines with Poles.—Some few practical hints may also be given on this subject, and before starting the men with poles, they should be taught how they are to manage them.

Let us suppose, for instance, that after running a line for some length on an object in the distance, we see that we shall shortly lose sight of it for some time at least, because we are going down-hill into a valley. Let the surveyor consider himself as having reached point A, D being the far object. Let the assistant or chainman, who is to be sent forward with a couple of poles, understand that he is to go down in the bottom of the valley at about B, selecting some spot which you consider you can see all the way from A to B. Point out to your chainman some object not very far off the line, and let him understand that he is to make use of such object as the first approximate guide in setting himself in line. Of course the object must be one that he will both see and recognise from B, for instance some remarkably shaped tree or large conspicuous bush; this will save time, inasmuch as the man will at once know pretty well whereabouts he is to go to get on the line. Show him, also, how he is to hold the pole, which should be in the following manner: The chainman should face the surveyor, holding the pole before him with both hands, as he can then scarcely fail to hold it upright, which is of great importance; he should not drive it into the ground when he first holds up the pole, and every time he moves it according to directions given by signal; on the contrary, the point of the pole should just touch the ground. Let him understand how you give your signals, and what they mean; if he is a new man, ascertain by trying him at a short distance, before you send him forward; otherwise, after losing a quarter of an hour or so in making signals which he cannot understand, you will have to call him back, as best you may, or go forward yourself to explain what you should have done before, and then return to A; if B is any distance at all, you may thus lose an hour or two in very fruitless work.



If you see a tall hedge or clump of brushwood down the slope of the hill, between A and B, and do not perceive any natural object which can be chained upon, let the man understand that he is to set up a white at such a place; perhaps there may be two or three such places between A and B. When you have given all these instructions, and satisfied yourself that they are understood so far, point out to your chainman what he will next have to do before returning. This will be to plant a pole at somewhere about C, which should be sufficiently high up the hill to enable you to see the far point D, when you shall have reached C; probably it will be as well for him to understand that he will have to set up a white or two up the slope of the hill between B and C. Let all your chainmen well understand that they are never to leave a pole until it is well fixed in the ground, and standing perfectly upright.

Do not suppose that you are wasting time by making your chainman understand as thoroughly as possible what you require him to do; an intelligent chainman is a valuable assistant; we have found sailors and soldiers make capital chainmen, and often much more useful for field work than men who have only been in an office. Before the man starts let him take forward with him all the traps you are not likely to require, which will leave yourself and your remaining men unencumbered, so that you will not so much miss the services of the man you have sent forward.

Now let us suppose the man off on his errand; whilst he is on his road to B, you may be finishing your field work at about A, and sketching in your field book some small portion of the work towards B, not too much, or perhaps you may have to rub it out again.

Let us now suppose the assistant has reached the place where he is to set up the first white, and that the point A is well in line. Observe that B is very much below the level of D; in looking down at B, without something to guide the line of sight, it will not be very easy to set B correctly in line between A and D; and we are now supposing ourselves to be at work without any theodolite at hand; the best substitute will be found to be a piece of twine, four or five feet long, with a heavy plumb-bob attached—we mean a heavy one, and not such a little pellet as is usually added by instrument makers to the theodolite, and which vibrates with every breath of wind; in short, a good lump of stone will do as well as anything. As soon as you have brought your chainman, roughly at first, but pretty nearly on the line, stand at about arm's length from A, with the plumb-line in hand, and the stone just hanging above the hole made by the pole at A, and which pole we suppose sent forward out of the way, bring the first white, by signals, in line with D; this done, hold up both hands and then drop them, by which your assistant knows that you mean, 'All right—drive it in there!'

The man moves on, and you may venture to lay out a chain or two, take a few effects where required, and sketch in a little more work.

When you see your assistant about to reach the next point, return to A, and repeat exactly what you have done before, and so on until your assistant has reached the point C. By this time you will probably not be very far from B, unless you have a good deal of field work to pick up, and your assistant may come back and meet you between B and C. Let it be observed that if you were to wait idle at A until all this were done, you would lose much valuable time.

Whilst on the subject of surveying poles, we may make the following observations, which will prevent our having to return to the subject for some time to come.

We will suppose we are pricking out a straight line, say a mile long, for a working survey, over nearly level ground, and that the ranging rods are to be set up at about every five chains. Evidently, after two or three poles have been set up, they will obscure the line forward, particularly at that level which we most require to see—that is, at the foot of every pole; therefore, as soon as each ranging rod has been finally set up in line, either it should be taken up again, and a peg driven in its place, or it should be made to lean to the right or left, so as not to obscure the view forward. Either this first plan should be adopted, or else that of commencing the pricking out by the ranging rods being set up at the far end of the line, instead of at the beginning. In this latter case, it is not quite so necessary as in the former case to pull up the ranging rods and drive pegs, or set them aside. The former course, however, is by far the most usual, and that which we always adopt.

Chaining.—Without good chain-work there is no good surveying, and the accuracy of a survey will be in proportion to the correctness of the chaining. We shall, therefore, enter pretty freely into the details of this part of the work, and, even at the risk of appearing tedious and dogmatical, we shall endeavour to mention everything connected with the subject.

Whatever chain is used—that is, either the Gunter's or the 100 feet, or the décamètre chain—there is no difference in the method of chaining.

The first thing to do is to loosen the cord with which the links of the chain are bound together. Let this piece of cord be put in the pocket, because it will be wanted again at the end of the day's work. It should be long enough to go six or seven times round the chain when put up, so that when an end of it is worn out, there may be still enough left to bind the links together. We always use a good strong strap with a buckle; but some persons consider this extravagant. Now this appears a very trifling detail, but the neglect of it often causes much waste of time. Unless the chain is well bound up, it is bundled anyhow into a bag, and the following morning it is with no little trouble and waste of time that the hundred links are disentangled. Indeed, the men often lose patience over it, and the chain often gets broken; not a little time is then wasted in mending it.

The strap having been put away, the two brass handles of the chain are taken in the left hand, the bulk of the chain being held in the right; a few links are then loosened out of the right hand, and with a jerk the rest is cast out. A chainman goes up to the half-chain mark, when the two halves are readily parted, and the work may commence at once. Any other method often leads to the links getting tangled together in the manner we have just mentioned.

Leader and Follower.—The management of the chain is intrusted to the 'leader and follower,' the first being the person who drags or *leads* the chain; the latter the one who *follows*, and gives directions to the leader where to set his arrow.

On starting, the leader takes the ten arrows in his left hand, and a handle of the chain in his right, and goes forward *towards* the pole at the other end of the line. It is of importance that in going forward he should be taught the absolute necessity of keeping his eye on the forward object, as this prevents his wandering off the line. Adopting this practice from the first saves both time and labour to a greater extent than may at first be imagined. The follower remaining at the starting-point with the other handle of the chain in his hand will check the leader as he gets near the end of the chain. The follower should be made to understand this, because otherwise the leader will be constantly overrunning the length of the chain, which will then have to be pulled back, again causing loss of time and labour.

On reaching the end of the chain, the leader may turn round and face the follower, with an arrow and the handle of the chain in his right hand.

The follower is standing over his end of the line, with his handle of the chain exactly at the starting-point. The offset staff, of which we shall speak presently, being fixed here, will assist in getting a fair start. A stout peg should be driven into the ground here, unless the survey is commenced at some permanent mark, such as the foot of the tree, a gate post, or some such object. It is a good plan to leave a white also at this place, for reasons to be presently explained.

Generally in practice the follower signals the leader, by bending his head right or left, which designates to which side the leader should hold his arrow. We suppose, for instance, the follower bending his head to the right. The leader moves his hand and arrow accordingly, probably too much. The follower will therefore have to lean his head to the left, and the inexperienced leader will very likely move back to where he was before, or nearly so. This will occasion great loss of time, and the leader should therefore be taught from the beginning that in moving back to the right or left he should not move his hand or arrow more than half the distance he has moved before. This ensures the arrow being fixed in its place very speedily.

Now all these things appear almost ridiculous trifles, and yet on them entirely depends whether a surveyor does two or three hundred chains a day, or not half that quantity; so that, in fact, instead of being trifling, they are of the greatest importance to the day's work; and not only this, but the men themselves have not half the labour to go through. Let your chainmen, therefore, understand from the first, and get into the following habits from the beginning. The leader, on starting with the chain in his hand, should keep his eye on the forward object for which you are chaining. This prevents his wandering a long way off the line. Whilst the leader is walking forward, the follower should have the other end of the chain in hand, so as to prevent the leader from overrunning his mark. When the leader has come to his chain end, and is setting his arrow according to the directions of the follower, he should only correct about half the error each time he moves his hand right or left, according to the directions given him by the follower.

We now suppose the first arrow to be on the line, when the follower calls out 'mark' or 'down,' at which signal the leader fixes his arrow firmly in the ground, unless, indeed, he happens to be on a road, when this cannot be done. In this latter case, he makes a cross at the point where the arrow should be, and lays the arrow down alongside of the cross.

If there is no offsetting to do on this first chain, the signal to move forward is given by the surveyor saying 'on.' The leader and follower both move forward, and both with the chain in hand, the leader steadily keeping in view the forward object, the follower checking him at once if he wanders off the line.

On coming to the end of the second chain, what we have just mentioned above is repeated—that is to say, about fixing the second arrow. Let us still suppose that there are no observations to book on this second chain, and that the word 'on' is again given. The follower picks up his first arrow, and both chainmen move on as before.

The end of the third chain being reached, the leader may save some trouble by setting himself very nearly on the line at once, by sighting himself by means of the last arrow left, and the white at the starting-point. If this is done, the follower will have but very few directions to give, if any. This work is repeated until the leader has expended his ten arrows, on driving the last of which into the ground he should never fail to call out 'change.'

At this signal the surveyor walks up to the last arrow, and there drives in his offset staff.

The follower comes up with his nine arrows. The surveyor counts them to see all is right. They are then handed to the leader, who also takes up his tenth arrow, the offset staff being left in the ground. If there be nothing farther to do on this chain the word 'on' is given, and all again move forward, and exactly the same thing is repeated as was done at the first chain. On taking up his offset-staff, the surveyor may have a white left, if there be one handy.

On this subject it will be found a wise precaution always to have a few slips of paper in your jacket pocket. As they need not be more than about 3 inches by 2, they are not heavy to carry. In the same manner each of your chainmen should always have about them a few short sticks, about a foot long, and the slighter the better almost. By these means a white is easily left at every ten chains, without having to look about for a stick. They need not be more than a foot long, because if they stand up high in the ground, they will be very conspicuous, and some one with nothing better to do will be sure to go and pull them up.

The object of this precaution is as follows: A surveyor on commencing a survey will have a lot of new men about him, whom he has not yet had time to instruct, and although he will keep his eyes sharply about him, some blundering *may* occur, particularly if he himself be not a well-experienced man. Suppose, for instance, that after chaining some thirty or forty chains, it is found that an arrow is missing. If no marks have been left behind, perhaps in a perfectly open country—as, for instance, a common—there will be nothing left as a remedy but to begin the whole of the work over again. The precaution we have mentioned prevents such a vexatious waste of time.

In describing the above method of chaining, it will be observed, that the leader, on coming to the end of his chain, turns about and faces the follower to receive his instructions and follow his signals; the men generally prefer this way of working, because it is less laborious than that we are about to describe, but we do not think it quite so accurate, as, for instance, for working surveys, though quite sufficiently so for preliminary surveys, unless there be very great carelessness.

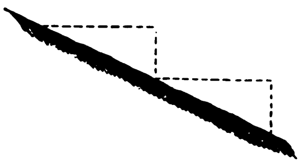
In the method of chaining we are now about to describe, the leader, on coming to his chain end, instead of facing right about, stands sideways on the chain, and thrusts out his right hand, holding the arrow and chain handle. To get the arrow into line, the follower calls out 'to you' or 'from you,' according as he wants the arrow right or left. There is, however, some difficulty with the men at first to get them to adopt this plan, and a good follower is required to carry out this method properly.

Necessarily if we want accurately the length of a mile of country, we must measure it with care; we may, however, be too fastidious, and thus consume a great deal too much time in doing a thing too well, or rather too fastidiously. For instance, in chaining over a rough country, through hedges and ditches, through furze and ploughed ground, it is quite impossible, without adopting special means, to make the chain lay in a mathematically straight line; the mere roughness of the ground will prevent it. Notwithstanding this, men who are new to the work, and often the best men because they are earnestly disposed to be careful, insist on their chainmen planting every arrow exactly on the line, *to an inch.* This is unnecessary, and leads to an immense waste of time, and is very fatiguing and harassing to the men.

That, however, which it is important to observe is, that every arrow shall be held upright both by leader and follower, and that the chain handles shall be held touching the arrows as every chain is laid; this is much more important in getting the true length of a line, than over-fastidiousness as regards the precise direction of the arrows.

Supposing that what we have hitherto said on the subject of chaining has been practically digested, we will now refer to chaining in hilly country.

On measuring up or down the side of a hill, we do not, in surveying, require the length of the sloping line, but the length of the horizontal base. The method usually adopted for chaining on sloping ground is called '*stepping*;' for instance, supposing that we are going up hill, the leader will stand at half or quarter chain, with his hand close on the ground; the follower, on the contrary, will hold his end of the chain up to his breast, but taking great care that he stands exactly over the right place for the chain end; to do this properly, the follower should hold the offset staff, or a pole, plumb over the precise spot; the first half or quarter chain being thus laid out, the follower lets go his end of the chain, but the leader holds on fast to the ground the half or quarter chain he has had in hand. The follower walks forward to the leader, fixes the point of the offset staff in the proper place, and the leader walks forward to take up the three quarter or other end of the chain. By the time he has done this, the follower will have fixed his staff plumb, and will be holding up the chain breast high, and the leader will only have to tighten the chain and obey the follower's directions as to position on the line. Of course if we were going down hill instead of up, the leader should hold up the chain instead of the follower, in which case it is the former who should be supplied with the offset staff. It will be understood that in referring to quarter, half, and three-quarter chain, we allude to the degree of steepness of ground.

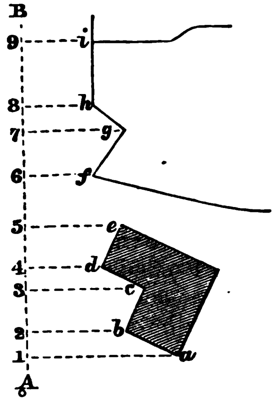


We have been particular in describing the method of stepping, because if not done properly, it is better left alone. The safer mode of making the necessary allowance in chaining up or down hilly country, and which we always adopt, because it is the easiest as well as the surest, is to take the angle of inclination, and make the allowance accordingly.

It is quite unnecessary to use any formidable instrument for taking the angle or making any calculation for ascertaining the necessary allowance. A little bit of cardboard is all that is required; it is graduated to degrees, and the corresponding allowance in links is marked opposite to the degrees; a little plummet hangs from the centre. You stand at your chain end, whilst your leader stands at the other; you look at his face, along the diameter of the little semicircle, and your chain follower reads off the allowance *marked* by the little plumb-line; the arrow is to be moved forward so many links accordingly. The greater the inclination of the ground, the less will be the corresponding horizontal distance; or the greater the angle of inclination the less the cosine. The plumb-line marks the difference between the length of the sloping ground and that of the horizontal distance for one chain.

OFFSETS.

Offsets in surveying are measurements taken from the chain to any object on the right or left, as, for instance, an angle or a bend in a fence, stream, or road; to a junction of fences, or the corner of a building, &c. Offsets are *always taken at right angles* to the chain, because this fixes them in direction as well as distance in reference to the chain line. For instance, in the annexed figure, 1 *a*, 2 *b*, 3 *c*, 4 *d*, and 5 *e*, are offsets to the corners of a building lying to the right of the chain line A B; if 1, 2, 3, 4, and 5, are given positions on the chain line, from which verticals of given lengths would fall on the angles *a*, *b*, *c*, *d*, *e*, it is very evident that we have only to mark off 1, 2, 3, 4, and 5, on paper, say 10, 20, 30, 40, and 50 links, and from these points draw verticals, each equal to 1 *a*, 2 *b*, &c., in order to lay down all the angles of the building on paper, accurately as regards direction and distance with reference to the chain, and similarly with regard to the bends in the fence at *f*, *g*, and *h*, and also the junction of fences at *i*.



It is by the distance on the chain, the right-angled direction of the offset and its length, that we are enabled to fix its position on paper exactly as it is on the ground.

This being understood, we may now refer to the subject of taking offsets, by means of which we fix all the details of a survey.

We may suppose, for instance, that we have been chaining on, expended a given number of arrows, and just laid the last chain A B.

The first thing to do is to *sketch* in the position of the building; the next is to ascertain the number of the chain on which the offsets have to be taken; to do this enquire of your chain follower 'How many arrows?' On getting the answer, suppose six, you know that the offsets are to be taken on the seventh chain; to be certain, however, that your follower has made no mistake, and that no accident has occurred, ask your leader, 'How many arrows?' his answer will be 'four,' if all is right.

The first offset, then, will be at 610, that is to say, if there has been no previous 'change.' But if there has been a change of arrows—that is, if ten chains have been laid previously—then the first offset will be at 1,610, and so on, if there have been already two or three changes. Evidently, therefore, it is necessary that every change should be booked, as 1,000, 2,000, 3,000, &c.

With regard to finding the position on the chain where the offset should be taken, stand sideways on the chain, and move backwards or forwards, until you come to the point from which a vertical points to the angle or bend to which the offset is to be taken.

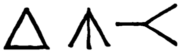
Offsets may be measured by pacing, with the tape, or with an offset staff; we prefer the last, although for preliminary or parliamentary work, we generally measure by pacing, and the student will find that after a little practice he can measure his offsets by pacing, quite as near as he can plot the work; of course it is understood that we have got ourselves into the habit of pacing a yard at every step. The offset staff will, however, be found exceedingly useful in determining correctly the point from which the vertical will lead exactly to the point required. We have set out offsets 300 feet long with the offset staff, and to make sure of the work we have several times tested the right angle with the sextant, without finding any appreciable difference.

The offset staff is besides useful for other purposes. For the Gunter's chain it is made ten links long, that is, 6·6 feet, when it makes a very useful leaping-pole. For the 100 feet chain the offset staff is made 5 feet long. It is shod at one end with an iron shoe steeled at the point. At the other end it has a shoe with a cleft in it, and a small hook; both these are useful, to attach the chain thereto in order to push or drag it through a hedge, exactly at that point which is on the chain line. It is a bad plan to throw a chain over a hedge, because generally this method gives very bad chainage. On long lines, on which there are numerous fences, a good precaution is to leave here and there a white in the hedge; this is done by passing a twig through a slip of paper and making a loop at the end of the twig to prevent the paper slipping off; when engaged upon works for which we had previously made the surveys, we have found some of these marks remaining, when every vestige in the shape of pegs driven in the ground, and broad arrows or triangles cut in the grass, had disappeared.

STATIONS.

Stations are certain marks which we leave in the ground along the various chain lines, to which we have to refer at a future opportunity. On an extensive survey, which may last some months, it is necessary that these marks should be more or less permanent. In arable lands there is no other way than driving a stout peg, and the chances are that it will be soon ploughed up.

Stations in grass lands are generally much more permanent; they may be made in either of the three following manners—a triangle, a broad arrow, and a crow's foot. In the first and third, the exact station mark is considered to be in the centre, whilst for the broad arrow it is considered to be at the junction of the three lines.



In woods and copses we do not require stations, unless the line is just on the outskirts of a wood; but it is always advisable to leave a few marks, in the shape of whites, on which the chainage may be marked in pencil. We may also here and there cut off a slip of bark from a branch, but so as to avoid mischief, which irritates landowners, farmers, and game-keepers more than is readily conceivable.

We particularly recommend the young surveyor to avoid cutting holes and gaps in fences, as it is pretty sure to cause unpleasantness, and very often leads to his being warned off the ground, a threat which a powerful landowner or wealthy farmer has not much difficulty in carrying out, and for which there is every excuse where wanton mischief has been committed. Besides all this, cutting gaps is sheer waste of time. A hole through a hedge no bigger than a man's hat, is as sufficient for the purpose of seeing, as a gap as big as a barn door. Let it be remembered that a gap cut in a quickset hedge takes many years to repair, and that even then, it will leave an unsightly mark in a perhaps handsome fence of thorns or evergreens; and a little consideration will make it evident, that farmers and landowners cannot be otherwise than irritated at such unnecessary damage done to their property. We have more than once seen such wanton mischief done in this way, that we have wondered the farmers have had sufficient patience not to take very summary means of stopping it.

There is another slight matter of this kind, to which we wish to call the attention of young surveyors; and that is to take care, with regard to himself and his men, that gates be not left open; when this is not attended to, cattle often get loose and do great damage, for which he may be liable.

As we have already observed, stations are left for future reference. They are so many points from, to, or through which side lines are chained for picking up the fences, streams, roads, buildings, &c., lying at some distance off the base lines of the survey.

On road, railway, or canal surveys, where the engineering surveyor is only for a few days in a locality, the marks left need not be of a very enduring character; indeed, if he takes the precaution of leaving a white at a fence crossing, with the chainage written upon it, and fastened in the manner we have already mentioned, perhaps nothing more is necessary for him to be able to find the spot a day or two after; it saves driving pegs or cutting marks in the ground. He should take care, however, to leave another white, on the line, in the next fence, so that the one may be seen from the other, as by this means he easily finds the line when he requires to do so, and by measuring off any distance from either of these points, he gets the exact distance, on the line, of the point which is the actual station, from or to which his side lines are chained.

For large enclosures with moderately straight fences, and where the actual measured survey is only some six or seven chains (Gunter's) on each side, but few stations are required, if any, because the surveyor when he has acquired some experience will pick up all the work on his base line, by taking long offsets carefully pitched; for preliminary surveys this will be the case very generally. The young surveyor will understand this the more readily if he refers to the scale to which such surveys are usually plotted—that is, six chains to the inch—and on which a distance of thirteen feet is represented by one thirtieth part of an inch. It is not an uncommon practice with many surveyors to guess the length of short offsets, and although we do not recommend this to the young surveyor, it must be admitted that the sooner he acquires an expeditious mode of measuring his offsets, the better it will be for him.

THE FIELD BOOK.

The field book is a record of the surveyor's daily operations. It is necessary that it should be not only accurate, but that it should give as correct a sketch of all the objects along his chain lines as possible. With the help of the measured distances, it should enable him to plot all the details of his survey exactly as they are on the ground.

Observe that there are two kinds of surveying field books; the one most in use amongst engineers is about four inches and a half wide, and about eight inches long, opening lengthways. It should be made of good thick paper, so that although a few showers of rain in the course of a day's work may wash out some of the lead-pencil, yet it will not obliterate the clear marks of the field work; the cheap books, made of thin blue paper, for this purpose, do not retain the imprint of the pencil, a little rain washes all out. We have sometimes been surveying in a drizzling rain all day, in November parliamentary work, and although the pages of the field book were thoroughly well soaked, we had only to dry them carefully before the fire in the evening, to be able to plot the day's work; the paper being thick, the work was as it were engraved on it. It is not necessary that it should be very thick; about a hundred pages is quite sufficient.

The field book should be paged from end to end, so that we may refer back to such a line on such a page. There should be drawn upon its pages from end to end, double lines in red, about half an inch apart. In this column the chainage on the chain-line is entered, that is to say, the chainage of the different stations, as also the chainage at which all the fences are crossed. The stations may be distinguished by running a circle round the figures.

Every chain-line in the field book should be numbered as well as every page, and for this reason—we may often have two and even three chain-lines on one double page, and on each line we may have stations denoted by the same figures; that is to say, that on each line we may have, for instance, a station marked 500. If, in a future page of the book, we were to refer to station 500, page so and so, it might be doubtful which of the three stations we referred to; but if the number of the line is also referred to, then there can be no doubt about the matter.

Although every surveyor almost always plots his own work, and indeed likes to do so, the field book should be kept in such a manner that any person understanding the work may plot from it. It should also be kept in such a manner that it can be plotted from for months, and even years if required, after the work has been done in the field. For instance, it may be required for parliamentary purposes many months after the work has been done, when it should be in such order that anyone may understand the work, and be able to compare the book with the plot survey. In cases where the field work has been sufficiently well done, it may be required to refer to the base lines, some two or three years after, for the purposes of the working survey for the construction of works. If it has been kept in such a manner that the stations on the base lines may be taken up again, it may save a great deal of work.

We point out all this to show the necessity of having everything clear and legible, and arranged in such order that any portion of work may be easily referred to and understood. We have twice had instances of plans having got mislaid or lost; but on application being made to the surveyor, he had only to refer to his field book to make out a fresh plot, although some years had elapsed since the field work had been done. Had not the field book been clearly kept, he could not have done this. In such cases one cannot trust to memory.

In order to keep a field book in this manner, there must not only be a system adopted from beginning to end, but the writing and sketching must be neatly done. The young surveyor will do well to accustom himself to use a fine hard-pointed pencil, to write his figures clear and small, to sketch in his fences at the angles at which they cross his chain-lines, to show the bends and angles of fences, roads, and streams as they exist, and to some extent to keep the work to scale. The experienced man can by these means get a great deal of work into one page; but we do not recommend the young surveyor to do too much of this at the commencement. Let him be satisfied with keeping everything correctly, clearly, and easily referred to. Let him be particular at the commencement of every line to enter correctly, whether, on starting from a line, he turns to the right or left; and when he returns to it, to enter the chainage of the station to which he returns, or which he crosses, the number of the line, and the page on which it is to be found. This will prevent his being at a loss when he comes to plot his work. So much as regards the order of the book-keeping; and be it remembered that at present we are referring to chain surveying only, without reference to instrumental observations.

Let him be particular as regards the field work that everything within two or three chains of his chain line is correctly sketched in, and that his offsets are taken *from* the chainage entered on the book, and *to* the right points.

We have now said everything that we believe necessary at present about chains and chaining, about poles and ranging rods, offsets, stations, and the ordinary field book, and we have only to say a few words about what we call the fair-weather field book.

This book is about the size of a boy's copy-book, and large enough to take in a few fields on every page, all being clearly shown, but from its size is but ill adapted for wind and rain. For fine climates, however, it is undoubtedly the best, inasmuch as it saves a great deal of cross-referencing from one page to another, as it is of such a size that there is no difficulty in getting in on each page twenty or thirty chains' width of survey.

CHAPTER II.

ELEMENTARY—*continued.*

CHAIN SURVEYING, WITH PRACTICAL EXAMPLES OF ORDERLY SYSTEM IN KEEPING THE FIELD BOOK—PLOTTING; FIRST LESSONS—CHAIN ANGLES AND TIE LINES—FENCE AND DITCH—INACCESSIBLE DISTANCES—BASE LINES.

To Survey on one Line the two Fields shown at Fig.* 1, *and to keep the Field Book, and to plot the Work on Paper.—Set out the line A B, so as to intersect the two fields at about half-way, by sighting on a pole at B, or better, to avoid loss of time, by picking out the stem of a tree or some conspicuous bush that may answer the same purpose.

Cast out the chain at A, and pass it through the hedge at some point in line with B; when the chain is brought tight, let the *leader* set in an arrow at the end of the chain, and on the line according to the directions of the chain follower.

The first offset we have to take is at 30 links, a line from which to the first corner on the left, will be at right angles to the line; this offset measures 110 links. Pass over the fence into the field, and standing on the chain and looking towards B, begin sketching part of the fences on each side, right and left, showing where they *diverge from,* or bend towards the chain. At 85 links on the chain, there is an offset at right angles to the main line, to the corner on the right hand; it measures 190 links, and is entered accordingly in the book.

There being nothing further to note on the first chain, the next is set out; and when the second arrow has been set, the surveyor or follower takes up the first arrow. At 150 links, there are two offsets to be taken, one on the left of 230 links into a corner, and the other to the right of 210 links into a bend. At 260 links, on the third chain, there is an offset to the left of 180 links, to an inward bend, and to the right an offset of 160 links into a hook in the fence. At 300, the end of the third chain, take the offset of 130 links to fix the direction of the main part of the fence on the right hand. At 420 links, an offset has to be taken to the curved bend in the fence on the left hand, which measures 190 links. At

490 links, there is an offset to the right, of 130 links, to an angular bend in the fence. At 650 links we cross the fence into the next field, which crossing requires to be sketched with attention to the bend on the right. To the left, this fence crosses the chain, square with the main line, and the distance or offset to the corner measures 90 links. At 640 links we have an offset to the corner on the right hand. We should here leave a station, making some mark on the grass, or driving a peg in the ground, as from or through this point we should probably have a line to take up the fences to the right and left.

At 730, we have an offset to the corner in the fence on the left, and so on to the end.

It may now be observed that all the offsets are taken square, or at right angles to the chain, and from given distances, on the chain, because this enables us afterwards to lay down the fences on paper, or to plot the work, exactly as it is on the ground.

And now to explain this portion of the work: Take a *scale of* 40, or four chains to the inch; draw a straight line on paper, A B, to represent the chain line; with the point of a needle, or a sharp-pointed pencil, prick off A, which represents 0, and then, consecutively, 30, 50, 85, 150, 260, &c. to the end of the line. And now take a little *offset scale,* which is generally two inches long, and of course to the same scale as the former, that is, four chains to the inch; place this at 30 links on the chain line, and quite square with it, and prick off 110 links, the length of the first offset to the left; move the offset scale on to the next mark on the paper, that is, 85 links in the field book, and prick off the offset to the corner on the right hand of 190 links; and now put the offset scale on the next mark, that is at 150 links, and prick off the offsets right and left, 230 links to the left, and 210 to the right. At 260 we have again two offsets, 180 links to the left, and 160 to the hook in the fence on the right.

In this manner we proceed to the end of the line, and if the line had been two or three miles long, instead of only eleven chains, it would be exactly a repetition of this kind of work. To complete the plot in pencil, we have now only to draw lines from offset point to offset point, as nearly as possible with curved bends or angles, similar to those we have in the field book. Hence the value of a correct sketching of the fences; and exactly as the offsets have been taken *square* to the chain line, and from the right chainage, so will the plot be proportionally correct.

The observations which we have already made on the *chain*, on offsets, and the field book, coupled with the above explanation, are quite sufficient, we trust, to enable the most inexperienced to understand the subject so far; it only remains for them to put this information into practice, by chaining a line through two or three fields, when they will much more readily understand the elementary portions of land surveying, as explained in the next few pages.

To Survey with the Chain only a large Enclosure such as we have shown in Fig. 2.—The first operation is to set out the lines, so as to get two triangles, as ABD, and ACD, two sides of which triangle are to intersect at E, somewhere about the middle of the enclosure. We may begin the chainwork at either of the points A, B, C, or D; let us suppose that we commence at A, cast out the chain, and work in the direction of C; the first point we have to enter in the field book is that where the line AC intersects BD at E; the distance to this intersection measures 590. Now, in order to find this intersection on the two lines AC and DB—and it is very important that it should be obtained accurately, because it is a check to the whole of the work—let the surveyor stand at A, and let his assistant or best chainman stand at D, and let a third person, with a pole, walk on towards the point C; by the one person making signals from A and the other from D, the third man by following the signals will be able to place himself exactly at the point, E, which is required; of course we suppose that two poles have been left at the points B and C.

We may now proceed with the chainwork, onwards from E to C, where we book the length of the line AC. From the point C, we commence a new line CD, turning to the right, which turning we show in the manner already explained under the head of field book.

On this second line we commence the offsetting, the method of doing which we have already very fully explained. On reaching the point D, carefully book the length of the line, which here measures 1,010. We now turn for A, to the right again, which gives us a third line in the book; take all the necessary offsets along this line, and on reaching the point A book also the length of this third line, which completes one triangle of the survey.

We now commence the second triangle, by chaining from A to B, taking the offsets as usual; at B book the length of the line AB, and at the same time we may look along the line BED, to see that the assistant has accurately ranged this line when he was at the point D. Now from B measure to D, booking the intersection when we come to E, 670, and on reaching D book also the whole length of line, measuring 1,300. Lastly, chain and offset the line BC, carefully booking also the whole length which measures 840. We have thus completed the survey.

Plotting and Testing the Work.—Take a straight edge and any convenient scale, say four chains to the inch, and lay off the line AC, equal to 1,260; to plot the first triangle, take a pair of compasses, and with them take from the scale the length of CD; with this length between the compass legs, describe from the point C an arc of a circle to the right. And now in the same manner take with the compasses and from the same scale the length of AD, 778, and with one leg of the compasses at A, describe an arc, intersecting the former one, which will be exactly at D, if the lengths have been correctly taken with the compasses from the scale. To make sure of this, take the scale, and setting the zero at C, see that the length of the first arc has been correctly set off; it should measure 1,010. Then set the zero of the scale at the point A, and ascertain in the same way that the second arc has been correctly set off; it should measure 778. From A and from C, draw straight lines to the intersection of the arcs; they will represent the chain lines CD and DB. Now to plot the second triangle ABD, take from the scale with the compasses the length of AB, and describe an arc from the point A and to the right of AD; then with the compasses again take the length of BD from the scale, 1,300, and from D set off an arc intersecting the former; as before, test the length of both arcs with the scale from A and from D, and if the lengths are found correct, draw in the straight lines with the rule from A and from D to the intersection of the arcs, which determines the point B, and the chain lines AB and DB. Now, with the scale, measure from A to the intersection E; it should give 595, and from B again measure to the intersection at E, which should give 668; now draw in the straight line BC from the point B to the point C, which should measure 840. If all this agrees with the field book measurements, the chainwork has been correctly done in the field and correctly plotted in the office. There only remains to plot the offsets, from the chain lines, in the order they have been taken in the field.

A somewhat more intricate example is shown in fig. 3; a four-sided figure will not conveniently take in the whole area, the figure of which is much more irregular than in the former example. From the points A and B we could get a view of the whole ground, and from these points the lines BC and AD were laid out, as also the bases AC and BD, intersecting at E.

The first line chained was A B, but from the irregular form of the fence on the right, we could only offset portions at the beginning and ending of the line. The offsets being taken, and the chainage completed to B, 1,920, we laid out the line B D; we had to prick out this line with whites because of a deep hollow at about the point E, from which D was not visible; but by standing ourselves at about the point G, and a chainman standing at about half-way between E and D, so that he could see us at about G, and also a pole left at B, we laid out this diagonal and then commenced the chaining from B to D, after entering in our field book, line 2, the proper sign for turning to the right, and the chainage at B.

We offsetted to the right from B to G, at which last point we left a station for running the line G F. We left our chain at G, after booking this station, 720, and proceeded to lay the line A C, which we did in the same manner as B D, and for the same reasons; we did so before proceeding further, in order to be able to book the point E, where the two diagonals intersected; at this intersection, we made a mark and returned to the station G.

Before proceeding with the chainage of B D, we ascertained that our follower and leader had *each* the correct number of arrows, and chained onwards until we reached the point E, where we entered in the field book the chainage which denoted the intersection of the diagonals, 1,340.

After this we had only to enter the intersection of a fence before reaching the pole at D.

Having booked the chainage to D, 2,660, we turned to the right again, entered 'line 3,' and proceeded onwards for point A.

It will be observed that there was a considerable quantity of offsetting here in order to get one bank of the stream, which was about 40 feet wide; moreover that the part of it near I was too far off to offset to, from the line D A; we therefore left a station at H, 800, and continued chaining and offsetting all the way, until we reached the point A, 1,795, which closed the first triangle.

We now start from A, turning to the right again; we leave a station at a convenient point F, 650, for running the line G F, book the intersection at E, 1,296, and chain on to C, the chainage at which, 2,500, we also enter, after noting where the chain cuts the fence. From C, turn to the right again, on for D, '2,660, line 2;' take the necessary offsets, right and left, and complete the chainage to D, 1,815; this gives the second triangle A C D.

We must now go back to C. Enter 'line 6,' turn to the left, and from the chainage at C, as measured from the point A, also noting in our book that we now chain on for the chainage at B, as measured from A to B.

These preliminaries being entered in the field book, we lay out the chain for B, sketch in the fencing as we proceed, take the offsetting right and left, at the prominent points in the bending of the fence, as they occur along the chain line, and complete to B, 1,765, 'or 1,920 line 1.'

This last line, tying the summits of our two triangles, will be the best check on the work done as yet.

We may now proceed to G, to chain the line GF. Here we enter 'line 7,' turn to the right (an obtuse angle), and also 'from' the chainage at G, 'line 2,' or for the chainage at F, '650, line 4.' These remarks in the field book will enable us to find the correct points on the plot. From G to F measures 895; of course we take the necessary offsets. We may now lay out the little line AI, 8, enter the point from which we commence, that is A, the beginning of the survey, and work on for I, in the direction probably of some convenient tree or bush at some distance off; from A to I measured 1,220. It is needless to observe that we took the offsets all the way to every bend in the bank of the stream, and sketched it in our field book.

From I, turn to the left for D, 795. Complete the work by chaining the little tie line HI, 465; this concludes the field work.

We may close these remarks by observing, that every time we complete a chain line, we should be careful to examine the number of arrows in the hands of our follower, and of our leader; this should never be omitted. Also, that every time we complete a line, we should enter not only the length of the line chained, but also the chainage of the station to which we have run, and the number of the line to which such station belongs; we thus know where to refer in our book, and also on the plot of the work. At the commencement of every line be particular in noting the number of the line, which we ascertain by referring to the antecedent one; and the particular sign, turn to the right, or turn to the left, as this enables us to lay off the line in the corresponding direction, when we come to office work. If this is neglected, after chaining any considerable number of lines, we have to trust to memory only for plotting the field work; this may either fail us altogether, or be very erroneous.

Plot of Fig. 3.—With a straight edge and sharp-pointed pencil lay down the diagonal BD; and here we may observe that there is always an advantage, when plotting, in laying down to paper the longest lines first; a *straight edge*—that is, a long straight-edged flat rule—should be used, in order that the line drawn on paper should be really a straight line; otherwise the trouble incurred in the field in chaining a straight line from point to point would be waste of time. The pencil with which the line is to be drawn should be sharp-pointed, in order that the line may be fine; if drawn with a coarse-pointed pencil, the line might be 10 or 12 links wide, and we should have to look for the centre of it every time we pricked off a distance from a scale. In drawing in the line, care should be taken to keep the pencil perpendicular, with the point close along the straight edge. This line being drawn on paper, we lay the edge of the chain scale close on it, and with a needle-point, or the point of the pencil, we prick off the length of the chain line, 'line 2,' 2,660, the zero of the scale will represent the point B, and 2,660 will be point D. Now open the compasses to take in from the scale the length 1,920, 'line 1;' place the point of one leg at A, and describe with the other an arc of a circle to the right of the base. Now with the compasses take the length of 'line 3,' equal to 1,795, and with one leg of the compasses at D, describe another arc to intersect that already drawn; the intersection will represent the point A; apply the scale to these two arcs, from B and from D, to ascertain that the lengths are correct, and prick through the intersection. It may be observed that in describing these arcs, it is better to use the points of the compasses, than the pencil points, because they give finer lines, and show more plainly the correct intersection. If we now draw the lines AB and DA, we complete the first triangle.

In the next place, we take with the compasses, from the scale, the length of AC, line 4, and from A describe an arc to the right; and now from D, we describe another arc, with a radius equal to 1,815, to intersect the former, which will give the point C; test them with the scale, and if found correct, prick off the point C, and draw in the straight lines AC and DC.

Lay the scale from B to C, and see if the reading gives the length of line 6, as chained in the field, that is, 1,765. Now lay the scale along AC, and ascertain that the intersection of the diagonals is correct; from A to E should measure 1,296; next lay the chain on BD; from B to E should measure 1,840. If these figures are correct, our work so far is right in the field and in the office.

On the line BD, with the zero of the scale at B, we may now prick off the station G, 720; and with the scale on AC, and the zero at A, prick off the station F, 650; draw in a straight line from G to F; place the zero of the scale at G, and ascertain that from G to F the distance scales 895.

We may now proceed to deal with the little triangle AID, and in order to do this, we make use of the same means as for the other triangles; that is to say, from the point A, we describe an arc to I, with a radius of 1,220, equal to the length of line 8, and from D, we describe an arc DI, with a radius of 795, to intersect the former; test the length with the scale, prick off the point of intersection, and draw in the lines AI, DI. On line 3, DA, prick off the station H, draw in the line HI, and with the scale ascertain that it measures 465, as shown in the field book.

This completes the skeleton of the work. We now open the field book at line 1, and laying the scale on AB, we prick off the chain distances at which the offsets were taken; having pricked off a certain number of these, we lay the scale, or the offset scale, square across the chain line, and plot off the corresponding offsets; join these points together in pencil, and they will give the line of fencing; treating all the chain lines in the same manner, you will describe all the fences round the field.

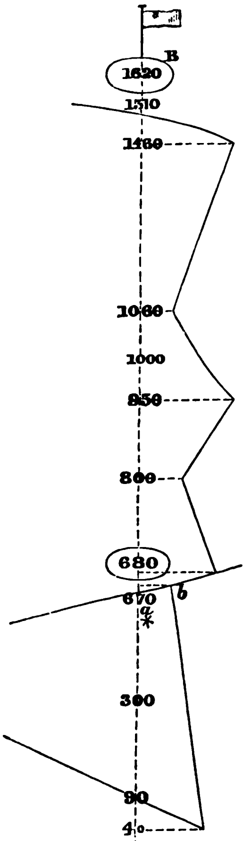
When this has been completed, the chain lines should be drawn in with red (crimson lake), and the fences with indian ink; the stream may be shown by a little cobalt blue along the banks.

Lastly, draw in the scale, and the plot plan is finished; from this, finished plans are prepared as they are required.

It may be observed that a very large pair of compasses would be required to describe some of the arcs mentioned above, particularly as the points of the compasses should be always held as vertical as possible over the paper. To obviate this, we use beam compasses, which will be described in another chapter, under the heading of Surveying Instruments.

The subject of chaining, offsetting, and keeping the field book, is one of the greatest simplicity to the surveyor who has had any experience, but to the beginner it is exactly on that particular subject which he stumbles most, when first practising his business. At the risk, therefore, of appearing tedious to the practical man, we shall venture, for the sake of the pupil, for whom we are chiefly writing, to enter into the most minute details.

Let us suppose, then, that the line AB has been set out by the side of some fences, as the first line of a survey. A pole has been left at B, which is considered a station. If the survey is of any size we shall perhaps require this station at some future opportunity; in this case the station ought to be secured in such a manner, that we shall find it when wanted.



If in arable land a stout stick should be driven in; not so stout, however, that it would require very heavy blows to get it any depth into the ground, for in that case it would split and very soon disappear; about three-quarters of an inch is a very good size, and with a few blows of a mallet, or even a stone, it may be driven so deep into the ground, that it will give some trouble to get up. We are obliged to be explicit on this subject, because on extensive surveys, where accurate work is required, these stations are important but very difficult to preserve; wherever there is an opportunity, they are generally pulled up for the sake of mischief.

If in grass lands, the stations should be marked in the manner already described, care being taken to break up and throw away, into a ditch for instance, the pieces of turf cut up; or they will be replaced and our station obliterated. These remarks about stations are particularly to be attended to when a station has to be left near a footpath.

We may now suppose that we have cast out the chain at A (as in the side figure), and that the leader has pushed his end of it through the fence, exactly on the line to be chained; otherwise we shall commence by chaining a crooked line. The leader is, of course, supposed to have the whole number of ten arrows in his hands, as the follower is at zero. The follower having given the proper directions to the leader about pitching his arrow, and the chain being brought tight before the first arrow is set, for it is no use doing so after, we may see about the offsets. There is one to take on the first chain to a corner on the right. As the follower has no arrow in hand, there will be no whole chain to book, only a fraction of a chain. To ascertain what this is, let the surveyor stand on the chain, facing the fence to be offsetted to, with his offset-staff in his right hand pointing to the fence, and right over the chain. With the staff held in this manner, let him move along the chain in the direction of the leader; the moment the staff held at right angles over the chain points to the corner to be offsetted to, we have the reading of the chain, which has to be entered in the field book.

In our example, this reading is 40 links, the point on the chain from which the offset-staff points to the required corner; this reading being booked, we have only to measure with the offset-staff up to this corner; book the measurement by the side of 40, which gives us the distance we shall have to lay down on paper, of the corner of the fence line from the chain, and the point on the chain line from which this offset measurement should be a perpendicular line.

This done, we come to the intersection of the chain with the fence; this is 90, the last brass *finger* on the chain, and we now cross over, having, however, left a mark at station A; we now come up to the leader. There is nothing further to do on this chain; he is therefore started afresh, and is supposed to know that he is not to wander in any direction, but that he is to walk straight on for the object at the end of the line; this saves a great deal of time in chaining.

The follower we shall at present consider to be the surveyor himself. We may here observe that where very accurate work is required, the surveyor should follow the chain himself, but this is not adhered to in ordinary work, because it is not sufficiently expeditious. We may also remark that no man will ever make a good surveyor who has not had a little experience both as a leader and a follower. It is only then that he knows at a glance as the work proceeds, whether his chainmen are doing their duty, and whether they are doing it properly with reference to each other; this is one of the things to attend to in order to obtain good and rapid chaining.

For instance, the leader may indulge himself by pulling a great deal to hard at the chain, which will distress the follower exceedingly; on the other hand, the follower, when straightening the chain, may jerk it so hard as to strain the wrist of the leader; this kind of thing often leads to the chain being broken between the two, and great loss of time incurred.

Again, in laying his chain, the leader may not hold his arrow upright; he may hold the handle of the chain and the arrow in such manner that the ring of the arrow very considerably overhangs the point of the arrow as it stands in the ground; this is very detrimental to anything like good chaining.

We may now proceed with our offsetting, and we might do so by chaining right on for the next fence, there being no offsetting absolutely required, because the fence on the right is straight; supposing, however, that a slight mistake is made at either of the offsets at each end, this error would be carried through from end to end; if we take an offset in the middle of the field at three chains, 300, then we have a check on any such possible mistake; the method of taking the offset is precisely the same as in the last case, only that we have to fix the perpendicular at the end of the chain, instead of any link at the middle or quarter; we have only one right angle instead of two, and if the ground happens to be sloping, a little extra care is required.

Before taking the offset, enquire of your follower, 'how many arrows?'—he will say 'two,' because you yourself are standing at the third. Before you book anything, make the same enquiry of your leader, he will say 'seven,' and for the same reason, that you are standing at *his* eighth arrow; these two enquiries are made to prevent one of two things, a mistake on the part of your follower, which might not be discovered at the right time, or an erasure in your field book, which always looks bad.

We may now 'go on' again; we must, however, look to see whether the pole at B, will continue to be visible as we approach the next fence; if this should be tall and thick, the chances are that it will conceal the pole from view, therefore select some object in the fence which you can sight upon; this done, the chaining may be continued.

With regard to the fence on the left hand starting from the 90 on our chainage, we take no offsets to this; it runs too much away from the work, and will have to be taken up by a side line from A.

Having reached the next fence, and the leader having crossed it with his chain, we have again to ask the follower 'how many arrows?'—the answer should be 'six;' if you are following yourself, as we supposed, you have only to look at the arrows you have in hand. Having done this you will ask your leader 'how many arrows?'—his answer should be 'four;' you are then safe to book your fence crossing, which is 670. A few links further on, 680, you have an offset to take to a corner and junction of fences; there is also another junction at about 675, but instead of marking this as an offset, you may measure from *a* to *b*, and enter this dimension, *without the letters*, in your book. At 680, you may perhaps have to leave a station for a side line, on account of the work to be taken up on the left. That a station has been made at any particular chainage, is noted by a ring round the figures, or by a straight line over and under. You proceed offsetting and chaining; 800 we shall pass over. You go on again until you come opposite to the next bend; before your reaching this yourself, the leader should call out 'change,' his ten arrows being expended. Having taken your offset at 950, you may walk up to your tenth arrow, and there drive in your offset staff. Book one thousand, hand over your nine arrows to your leader, who also picks up the tenth, and goes on again. In this manner you reach the end of the line.

In good chaining, the leader should hold his arrow close to the end of his chain, but *within* it, and the follower should hold his arrow close also to the end of the chain, but outside of it. It is unnecessary to make the leader move his hands to get into line, until he is on the line himself; then the hand should be made to move with chain handle and arrow in it. Before the leader comes exactly to the end of his chain, the follower should give it a slight check.

In keeping field books, we always commence a line at the bottom of the page and write upwards, just as the chaining and the country through which we are working lay before us.

In sketching in fences, always stand on your chain line facing your fore object; this enables you to sketch, in your field book, the fences, roads, streams, &c., very much at the same angles as they lay naturally with the chain; you will find this a great help in plotting. As you chain on, do not sketch in too much of your fences at a time, two or three chains forward are quite sufficient; this obviates erasures in the fencing. You will find that in chaining forward, the fences, and the bends in them, are different to what they appear at a little distance. One of the most valuable good habits of surveying is the practice of careful sketching in your field book, but it is only to be acquired by practice.

Great care is always required in booking the stations, which should always be made at ten or at least five links; also at the commencement and ending of lines, and in showing the angle, obtuse or acute, at which you turn to the right or the left for the next line on the Survey.

To know these things practically, they must be practised industriously in the field, and we again advise the young surveyor, before reading too much, to have a few days' field practice, if only by himself and a lad to lead his chain; it will only be then that he will understand the value of the hints and suggestions with which we are now endeavouring to supply him.

The outlines of the figures we have hitherto treated have been sufficiently symmetrical to enable us to get favourable intersections at about the centres E; that is, the angles have been neither too acute or obtuse, they are greater than 45 degrees and less than 90. This kind of figure, however, by no means occurs always. In fig. 4, for instance, we have an elongated shape, which would not admit of such a favourable intersection of diagonals, and we assume another method.

We here lay out the base A B, to go through the length of the enclosure, and sufficiently near the stream to be able to offset it to along its whole length, that is A B. We now build up the triangle A C D by setting off D A, equal to some six or seven chains, and by putting up a pole or selecting some natural object at about C. A D, A C, and C D, should be about equal, that is, as far as may be approximated by the eye. In the next place select the station E, up the road as far as you can see; fix the point F on the base, so that E F shall be somewhere at about right angles to A B. We may now build up the little triangle B G H, in the same manner as we did A C D.

We may now chain all these lines in the manner we have set them out; the tie or check line will be E H.

In plotting this work on paper, we first lay off the base A B, describe the little triangle A C D, open the compasses to the length C E, and from C describe an arc at about E; do the same thing for F E, which will give the intersection E, and as correctly as the field work is correct.

Now describe the little triangle B C H, which will determine the point H; if the whole has been done correctly, a scale placed from E to H will give the same length as the field book.

Suppose, for instance, that an error had been made in chaining A C, such as a mistake in the arrows, and that 900 had been booked instead of 800, the point C would be higher up the road than it should be; the laying off of the point E would not help us to discover the error, and this point also would merely lay too high up the road without our knowing it; but immediately we lay the scale from E H, we discover the error, as E H would scale too short, unless indeed we had committed an exactly corresponding error with the triangle B H G by making G H a chain too long. If we had reason to fear any such very out-of-the-way errors, we should check the whole work by a chain line from H to F, which would check the position of the point H.

This brings us to the subject of *chain angles*.

In the triangle ABC, fig. 5, A, B, and C are chain angles, the measures of which, for our present purposes at least, CB for the angle A, and CA for the angle B, and AB for the angle A. Similarly, in fig. 4, the angles at E are chain angles, but subtended by two sides each—that is, CD and DF; and HG and GF. In fig. 5 the base AB is 15 chains, and AC and CB are 12 chains each. There is a station at D, and a tie line is measured from C to D to check the measurements of the triangle. It is our purpose to show that a tie line so placed would be quite insufficient.

We may suppose, for instance, that an error of a chain has been made in the measurement of AC, as shown at A*c*—that is, that A*c* has been measured as 11 chains instead of 1,200. The measurement of the tie line to the point D is no sufficient check, for CD and *c*D are very nearly equal.

But if, instead of the station D, we have a station at E, somewhere about the centre of the base, the tie CE is a sufficient check, for CE is much longer than CE, and the difference in the length is palpable. An effectual tie line, as a check, may also be measured from *d* to *e*, the difference between *fg* in the triangle which is wrong, and *de* in the triangle which is right, is too palpable to admit of a mistake.

In the acute-angled triangle, fig. 6, we have exactly the same operations. An error of a chain in either of the sides AC or BC is not discoverable by the measurement of the tie CD, for in the triangle ACB, in which B*c* is a chain short, the tie *c*D is very nearly equal to the tie CD; the difference at least is so small, that considering the small errors to which all chainage is liable, the chances are that one tie is as correct as the other to all appearance. But a tie from C to E is more satisfactory, the difference between CE and *c*E being much more appreciable. This difference, however, is much less satisfactory in fig. 5, because the angles at C and *c* are so acute that the exact intersection of the lines AC and BC is not so self-evident on the paper, or indeed on the ground, where a very slight variation in the *direction* of the lines would make a considerable difference in their lengths.

Similarly, *de* is an insufficient tie line, being very nearly equal to *fg*, although *c*B is one whole chain shorter than CB. It would not be much better if this tie line were much lower down in the triangles, the difference in the lengths not being sufficient.

The above makes it very evident that in chain surveying acute angles are to be avoided as much as possible. It is not quite so important in surveying with instruments, though even then undesirable, because a theodolite placed at B, either in fig. 5 or 6, would discover the mistake.

To prevent errors in such a triangle as fig. 6, it would be necessary to measure a tie line A*e* or B*d*, as well as CE.

To Survey a large Enclosure, such as a Wood, by Chain Angles.—We have such a case in fig. 7. Lay out four lines enclosing the wood; the nearer they cross on the square the better. Take the intersection *b* for a station, make *b*A and *b*D some given number of chains, say four or five, so as to be some fair proportion of one of the sides of the quadrangle; measure the side AD, and do this carefully, for it is to determine the measure of the opening of the angle *ebf*.

Observe here that the paper work will be much more difficult to plot than it will be to do the field work. Having the sides D*b*, *b*A, and AD, we can describe the triangle D*b*A, and thereby determine the direction of *b*C and *b*B; but at the points C and B any slight error in AD will be magnified in the proportion of the lengths of the greater lines, and therefore to check the chain angles, set off say a couple of chains from *b* to *c* on the line *b*C, and from *b* to *d* on the line *b*B, measure A*c* and D*d*, and also *cd*, if a *clear* straight line can be had through the corner of the wood.

Observe that these tie lines will all be checks on the plotting or the triangle D*b*A. Chain out BC, making *be* any equal number of chains, if not inconvenient for the lines *ei* and *f*F. Set off *e*C and *eg* some three or four chains each, measure *g*C, chain the line *ei*, leaving a station at *h*; set out E*fh*F through *h*; set off *hi*, *h*F, and *hk*, each equal to some three or four chains, and measure *i*F and F*k* to determine the opening of the angle *ih*F, and check the measurement. Now chain *hf*, producing the line E, and making *f*E some three or four chains; the same thing with regard to *f*B, and measure the tie line BE. Finally measure the line *f*C, completing the quadrangle.

Of course it will be understood that in chaining the lines *be*, *eh*, *hf*, and *fb*, we have taken all the offsets to the fences, as also the fences intersected.

To Plot the Work.—Describe the triangle D*b*A. Through *b* draw A*b*B and D*b*C, prick off the station *c* and *d* with a fine needle point, and apply the scale to A*c* and D*d*, as also to *cd*, if this last line has been measured. If these lines are found to agree in measurement with the field work, we may assume the angle B*b*C to be correct. Prick off the chainage *be* and *bf*. From the station *e* set off with the compasses an arc of a circle, with a radius equal to the chainage of *eh*, and from *f*, with the compasses, set off an arc with radius equal to *hf*;

prick off the intersection which determines the position of *h*; through *h* draw *gi* and EF, make *hi* and *h*F of their proper lengths, as also *f*E and *f*B. Now measure all the lines—that is, C*g*, *k*F, F*i*, and BE. If these agree with the field book, then both the field work and the plot may be considered as correct.

In fig. 8 we have an area similar to that of fig. 7—that is to say, it is inaccessible internally, being a large lake; but although we cannot chain through it, we can see over it, which offers some advantages in making the survey and in checking the work.

We may commence the work by setting out the four lines which enclose the area to be surveyed, and we may set out the triangle D*b*A, by producing the two sides C*b* to D, and B*b* to A, making each line produced of a given length, and then measuring the third side DA. After having proceeded with the four sides and the chain angles in the manner described above, we may check the work in the following manner:—

Set out the line from *i* to D, and by standing at station *f*, ascertain where it intersects *fh* and *fb*, measure *ik* and *hk*, also *db* and *b*D. In the same manner set out BC, and ascertain where it intersects the line *fh* and *eh*, measure B*l* and *fl*, also *e*C and *em*. Other lines may be set out in the same manner. If the field work has been correctly done and plotted, all these little tie lines will measure on paper the same as they do in the field book.

Here, again, we would recommend the pupil to practise in the field before proceeding further with his reading. By doing this he will make himself familiar with the use of the chain and the poles, and in setting out lines of some fifteen or twenty chains before coming to long bases; he will thus get accustomed to the little difficulties to be overcome in practice, in laying out lines and in chaining them, in offsetting, and keeping his field book neatly and in an orderly manner, so that it may not be as useless as an entangled cobweb. By plotting his work, and attending to every tie line as a check, he will get used to straight-edges, scales, and compasses. He must not allow himself to be led into the delusion that because he has read these few elementary pages, he is perfectly competent to undertake a survey of even a dozen acres. But if he puts our recommendations into practice, he will soon overcome the first difficulties of field work, and he will be far more able to follow us in more complicated matters, and to apprehend the application of our various suggestions. In offering this advice we feel perfectly safe, because we well remember our own deficiencies when making our first practical field-work experiments, now many years since.

FENCE AND DITCH.

In order to keep our first instructions as clear as possible, we have hitherto avoided complicating our explanations with any reference to 'fence and ditch.'

Supposing we are standing in a field, with a fence between us and the ditch, we may, as a general rule, consider that the ditch belongs to the field in which we are standing; consequently, it would not be correct, in surveying through such fields, to chain or offset up to the centre of the fence as the boundary of the field. It is the brow of the ditch which should be taken as the boundary; but although ditches are often eight or ten feet wide, the allowance made for the width of ditch is generally taken as six links of Gunter's chain.

Supposing, therefore, that in the case above we chain up to the fence, and find that the intersection of the 'stick' or 'quick' is 84 links, then we should add 6 links, and enter 90 in the field book; similarly with regard to offsets.

But let us now suppose that we are coming from the other way—that is, that we cross the ditch before reaching the fence. Then, instead of adding, we should deduct the six links. If, for instance, the chain crossed the quick or centre of the fence at 84 links, we should make a deduction of six links, and enter 78 in our field book.

It must, however, be carefully observed that this allowance of six links is on the supposition that we are crossing the fence on the square; if we cross a fence very obliquely, a much greater allowance for the chain intersection will be necessary. Where we have reason to be particular in this matter, it is best to put the point of the staff square into the fence, and see where the sixth link on the staff will intersect the chain; this will give us the correct boundary.

In making working surveys, or for the transfer of property, this matter of boundary is to be carefully attended to; the neglect of it might render the survey worthless.

We have said above that six links is the allowance to be made, generally. In some cases, however, a greater allowance has to be made, and, as a rule, where we have careful surveys to make, it is safest to make local enquiries. Where we come to palings, we have only to remember that the nails are driven from home, in order to guide us about the ditch. For walls, we take the wall as boundary, unless it happens to be a party wall; but this is a matter in which it is very easy to obtain accurate information by making proper enquiry.

Where we meet with ditches on both sides of a fence, it should be shown on the field book, and information obtained at the first opportunity.

INACCESSIBLE DISTANCES.

In surveying, we often find that we come to distances which we cannot obtain the length of by *direct* admeasurement. For instance, we may come across a pond, the corner of a wood too thick to chain through, a building, or a river, &c.

In fig. 9, the chain line AB comes across a pond, perhaps four or five chains in width. Take any convenient point *c*; set out the line *cd*, so as to clear the edge of the pond; on coming to about *e*, see where you can clear the edge of the pond again, so as to be able to chain to *f*; make marks at *c*, *e*, and *f*. Now chain *ce*, and make *ed* equal to *ce*; make a mark at *d*; set out *eg* in line with *fe*; measure *fe*, and make *eg* equal to it; make a mark at *g*. Now ascertain by measurement the length of *gd*, which is equal to and parallel to *cf*. This is one of the little matters where the chainage often gets wrong by mistake being made with the arrows.

Let us suppose that in chaining along the base line AB, we find that the leader's end of the chain will fall in the water. Lay the chain in line with B, as far as it will extend to the edge of the pond, and let a chainman go round to the other side, to set up a white, some few chains forward. Select a point on the chain, a *forty* or *fifty* links, from which you can see clear of the edge of the water, towards *d*; say that up to *c* the chainage is 2,450; enter this in your field book at once, observing first whether your leader has six arrows in hand, there being none at the forward end of the chain, which would be in the water if the chain were stretched out. Chain on towards *d*, and find a station at *e*, from which you can clear the edge of the water in setting out *fg*; make a mark at *e*, and make *ed* equal to *ce*. Now move on towards *f*, and make a mark there, exactly in line with B (the white sent forward), and with *c*; drive a peg at *f*, and set out the line *feg*; measure *fe*, and make *eg* equal to it. Measure *gd* which is equal and parallel to *cf*. Let us suppose that it measures 368 links; then 2,450 + 368 = 2,818.

Then the chainage of the point *f* will be 2,818. Take the chain up to this point, and lay the end of the eighteenth link on the chain at *f*; see that your leader has two arrows in hand, and your follower eight. Lay your ninth chain, measure from *c* to the edge of the pond, and also from *f* to the other edge.

The whole of fig. 9 will require to be sketched in your field book, in order that from the line *ce* and *fe* you may get in the form of the pond at the end where your chain lines have been laid. The chainage of the base may then be continued.

Instead of *c* falling at 2,450, say that it is 2,850; the ten, or change of arrows would have been between *c* and *f*, if the line had been clear; 2,850 + 368 is equal to 3,218. You will have to book 3,000 as being in the pond. As before you will have to lay the eighteenth link of the chain at *f*; your leader will have to take forward eight arrows, lay one at the end of the chain, and your follower will have to retain two.

In fig. 10 circumstances are rather different. We have here a river to cross on the line AB, and we must adopt a different method to obtain the width of it.

Let a chainman go forward with a pole, which is to be firmly set up exactly on the line AB, at about the point C. Then make ED equal to a given number of chains, say four; set up DG exactly at right angles with the base line, and make DG a given number of chains, say three. Set up a pole at G, and another on the line EF ranging true with GC. Measure EF with care, and say that it is equal to 442. Now multiply GD by DE, that is 400 × 300. Divide this by EF − GD; the quotient is equal to DC.

As a formula we shall have

$$\mathrm{DC} = \frac{\mathrm{GD} \times \mathrm{DE}}{\mathrm{EF} - \mathrm{GD}}.$$

In the present instance DE will be equal to 845.

This problem is very clear in itself, but requires some care in carrying out in practice. If GD and EF are not parallel and vertical to EC at the points D and E, there will be no truth in the results, and if the bank of the river ED is rough sloping ground some care is required to make these lines what they should be, that is, for careful surveying. We are not now referring to approximate work, the practice of which the student will gradually drop into quite soon enough in all probability; this we shall refer to hereafter.

In order to test GD and EF, produce them to K and J, making DK equal to DD, and EJ equal to EF; if all is right, C, K, and J, will all range in one line as well as CGF; if otherwise, there is an error, which must be corrected.

In setting up perpendiculars, more particularly on sloping ground, and where no instruments are made use of, the following method of using the chain may be had recourse to.

From D, set on the base line twenty-five links on each side of D, so that *mn* shall be equal to half a chain; at each of the points *m* and *n* pin down a handle of the chain. Take the fifty mark in hand, and draw the chain out towards G, until the lengths *mf* and *nf* are equally taught. A line from D, through *f*, will be a perpendicular to DC.

Another method for measuring an inaccessible distance is shown at fig. 11, where AB, the base, crosses a river, the distance EC being inaccessible. Having fixed on the points E and C on the opposite sides of the river, and exactly on the line AB, range out any line as CD, and set up a pole at any convenient point as G. Measure DE, and at half the distance F set up a white, perfectly vertical, or a pole. Set out GH, measure GF, and make FH exactly equal to it; produce DH to intersect the base at I.

Measure HI, EI, and EG; then HI is to IE as EG is to EC.

If the base had been the line DC, instead of AB, the length of GC might be ascertained by the same problem, for IH is to HE as EG is to GC.

Laying out the base lines of a Survey over an extensive area generally requires very considerable attention, more particularly if this area is very irregular or unsymmetrical; it is often necessary to perambulate the ground once or twice before deciding on the lines which are to compass the survey, or on the diagonals. It is, however, quite possible to waste time by doing this too often, or at least oftener than is absolutely necessary in practice to procure a good survey.

There are two or three maxims to be attended to in laying out such base lines; the diagonals for instance should intersect near the middle of the survey; all angles should be as nearly as possible equal to sixty degrees, and the ground should be divided into as few triangles as possible. Where we have such areas as are shown in figs. 2 and 3, acting on these maxims offers no difficulty; this however but seldom occurs, and instead of figures which may be encompassed by quadrangles of pretty nearly equal sides, we often meet, on the contrary, with areas for which they would be totally unsuitable.

For instance, in fig. 4, diagonals would intersect at very acute and obtuse angles, which renders the correct intersection very uncertain; and in fig. 12 the quadrilateral has two opposite sides very unequal, and the intersection of the diagonals is very far from the centre of the survey. A more suitable figure is the triangle EFB. This would be ascertained by going once over the ground, even supposing there was no former map to consult. Even this much shows the advantage of walking round the boundary of the area to be surveyed.

If to this we add the precaution of examining from the interior, selecting for this purpose the highest ground, and noting objects selected on first going round, the direction of the diagonals or intersecting bases will be pretty well defined.

Having, for instance, decided, in fig. 12, on a triangle instead of a four-sided figure, we know, from what we have already observed in a former page of this chapter, that the intersecting bases G I and B H should fall as near as possible at about the middle of the sides A B and E F. This point being settled, we have only to examine the ground a little to see where we can lay out these lines, so that they shall run sufficiently near fences, streams, &c., in order that we may pick up as much offsetting as possible along such base lines. We must also as far as possible see that they run near, but not through, the intricate portions of the survey, so that we may have stations conveniently near such work, to start secondary lines through. For instance, unless the survey is *very* extensive, the bases F G and B H should lay so that we may run useful lines from them into the enclosing bases E F, F B, and B E. If the main bases of the survey were a couple of miles in length, these secondary lines would not be more than forty or fifty chains. A few of these so completely divide the principal triangles, that the remainder of the work is very simple. Hence the advantage of a careful examination of the ground in the first instance.

Not only do we thus obtain symmetrical and well-balanced triangles, all the sides of which are well checked by lines which are useful base-lines, but we also reduce the labour for the remainder of the work; there is no going backwards and forwards to see where such lines should lay; they, the secondary lines, are of such inconsiderable length that at about the middle of them we can see both ends, and the work they will pick up by offsetting; there is but little trouble in sighting them, and one or two poles or very few whites are all that will be required.

For surveying by chain only, the system of dividing and subdividing triangles, by similar figures, is the most suitable; it is the most easy, unless your triangles are badly set out; errors are readily open to detection, and it is the easiest and most accurately plotted.

We very often, however, meet with surveys on a large scale, the outlines of which are so unsymmetrical that it is almost impossible, without great labour, to enclose them or divide them by triangles, with well-proportioned sides and angles. We meet with a case of this kind in fig. 13. After going over the ground two or three times, we found it best at last to set out a couple of diagonals, A B and E D, intersecting at C, pretty nearly at right angles. The sides A D and D B gave us two good triangles, and the main triangle A D B was tested by the position of the tie D C.

It was, however, evident that in plotting this triangle, and the lines so far, we should have to lay off C E by producing D C. We therefore had to check the position C E; this was done by chaining a line from E to G, laid out at the same time so as to take up some of the fencing by offsets; we took a further check by chaining a line from L on E C to the other end of the base B. This line L B had very little work on it, but it was a good tie. The exact position of L was determined, not only because it would pick up the fencing near A, but also between F L, in the interior, though this portion of the work is not shown.

In fig. 14 we have another unsymmetrical outline, but it was pretty well enclosed by the main triangle A B C, with fairly proportioned sides and angles. We had now, however, to deal with the hollow D N M G; to get at this, we threw up the internal triangle D F G, producing D F to E, which gave us a good check on the main triangle, the whole of which was further tested by the tie F L; further, E F and F L are tie lines for the smaller triangle D F G, had this been needed; but the line D E being fixed in position by chaining from station D on the line B C to station E on A C, its being measured correctly would to a great extent prove itself; it was essentially a tie line. G also is a fixed point, being a station in B C, and F also has been made at fixed points well ascertained, by being a station on the tie line D E; therefore F G is a tie line, proving the former work, and at the same time its own chainage. It was safe to produce such a line for the short length G H, so as to fix the point H, and the length and direction of G H were tested by the tie line from H, through the station I on to the station K, the three points being all in one line.

It may thus be seen that very good work, even on a rather extensive scale of land surveying, may be done with the chain only. This is in a great measure effected by the surveyor combining in his mind, from the first, the secondary lines with the first. In the course of his first walk over the ground, which he should take leisurely and with as much observation as possible of everything in the shape of marked objects, particularly prominently shaped or remarkably coloured trees. On a second examination, by having in mind the position of such objects, he will probably be able to determine pretty nearly, if not quite, the position of such points as A B C, by standing himself at one of these, always supposing however that he has not a great wood on one of the outside lines, as this would probably alter the face of things altogether, and lead him to adopt a quite different form.

If the points A, B, and C, are all above the ordinary level, this will of course materially assist our operations; or one of these points being on high ground may be made of great service in giving us something like a view of the other points. Instead of being on high ground it may be the reverse, and every one of them may be in a hollow.

By two persons, however, standing on the highest ground, about one hundred yards apart, on either side of the three bases, they may approximately sight each other, so as to determine pretty nearly how much any two distant points, as for instance C and B, will require shifting to the right or left; and similarly with regard to the other two lines B A and C A. We do not recommend too much time being spent over this operation, for instance as to whether A, B, or C shall be two or three chains, this or that way; at the same time let it be well remembered that a total disregard of the subject may have for one consequence the chaining of lines through a blank country, that is, on which very little offsetting may be picked up, which will necessitate parallel lines being chained for taking up the offsets only, and which may nearly double the amount of work.

For this kind of work, that is, surveys of an extensive area, we always have our poles about twenty feet long; we have described them elsewhere. In fine weather we have two of them tied together, one above the other; this gives us about thirty-five feet, and with a little red and white flag at top we can generally see this a mile or two off, above the fences, particularly if we take the trouble to look for ground a few feet above the ordinary level.

In windy weather, however, the matter is more troublesome, and we want something stronger; for this purpose we often hire two or three of the lightest scaffolding poles we can secure, and tie one of our flag-poles to these. Unless we can find a tree handy, against which we can lean this long pole for an hour or two, it may be necessary to leave a couple of men to hold it up, after we have partly stayed it as well as momentary requirements will admit. It does not take much time to do this, nor is it very expensive; even on a long base and in a hilly country, one day should completely establish the position of a good base.

Of course this is very dull reading to the practised surveyor; but probably he will remember the time when all these little suggestions would have saved him much time and labour, as well as results less satisfactory than they would have been if some of these precautions had been adopted.

We have often to make surveys of estates not within a ring fence; the property lays in scattered groups of fields, but they require being laid on the map in the exact position in which they are situate on the ground. To some extent, therefore, the properties around require to be partially surveyed, at least chained through, particularly where there is an opportunity of purchasing any of the property outside of the estate. We have an example of this kind in fig. 15. After what we have already said on the subject of bases, the reader may judge for himself how some of these cases have to be managed, and he will also see that there is much more trouble and expense attending these surveys, acre for acre, than in an ordinary case.

We will take one more case deserving consideration. This was a survey on the coast, where there were some lofty cliffs which required to be included in the survey, as well as the foreshore as far as low-water mark; there were, besides, two deep and wide ravines projecting inwards from the cliffs; the outline and base lines are shown at fig. 16.

There was some doubt about the two base lines A B and B E.

Almost the whole of the ground was covered with wood. B E was set out as the first base, but as the work progressed it was considered too far from the boundary; it was, however, carried out throughout its whole length, because it took up a considerable quantity of offsetting, and because it was a good line to start others out of towards the cliff, without the imperfection and trouble of sighting and chaining lines through the woodlands; but it was in no way considered as a tie on the great triangle A B C.

The base B C gave us no trouble; the main tie on the great triangle was the line F G.

We made use of the two bases A B and E B by running lines which intersected and tied them at the same time that they gave us the offsetting for our very irregular boundary. For instance, we had the triangle L N B, of which the side L N out of B E intersected A B at M; and L K intersected it at O; between P and K was all thick wood.

With regard to the lines A C and D C, the relations were somewhat analogous to those of A B and D E. On A C we had two bad places, the crossing of the ravines, where the cliffs were very deep, about seventy feet, and where moreover they were full of brushwood and very rugged. This line was only sighted throughout, and accessible portions were chained as C W and T Q, &c.

Another base, C D, was chained, and tie lines X U V W, R S T, &c., were run tying the whole; these lines took up the fences by the side of the ravine, which at S V was shallow and clear, and gave us no trouble.

These few hints have been given to explain how by a little study, even disadvantageous circumstances may be made use of without entailing too much trouble.

We have already alluded to the cliffs and foreshore, which required connecting with the main survey.

This had to be done with some considerable care, because we had to show the foot of the cliffs, high and low water mark, and all the ledges of rock, which consisted of valuable limestone valued at 7*s.* per ton.

A valuation of this was required, and to obtain the means of doing this we had to take numerous sections to show the quantities of rock above low-water mark at spring tides.

The theodolite had to be used to set out the projections of the bases and secondary lines down below the edges of the cliffs. Although the subject of surveying with instruments is beyond our present range, and as we shall very shortly have to describe the theodolite and its use, we will refer shortly to the means employed, to prevent our referring to this particular subject further on.

The lines B C, X W, &c., and some of the secondary lines, had to be produced towards the sea as far as possible; they were therefore produced first to the edge of the cliff, which were in all places very abrupt, and in some cases nearly vertical. A few poles were set up on the back lines, and the theodolite set up as near the edge of the cliff as possible; the instrument was planted so as to make the axis of the telescope range true with all the poles; the telescope was then reversed, and two poles set up in line, one as near the foot of the cliff and the other as far out on the ledges of rock as possible. Of course the lines on the foreshore uniting these points were all tie lines.

But we had also to find the horizontal distances between these points and the edges of the cliffs; the lengths, some of them upwards of 350 feet, were all measured with long line twine, which was afterwards measured with the chain; these lengths were all diagonal, and not the horizontal distances required; the angles of inclination were therefore taken at each point, and the horizontal distances were reduced in the following manner.

The theodolite being set up at A, fig. 16*a*, its height above ground was measured with a tape; a levelling staff was held at B, and the intersection of the hairs of the diaphragm was made to intersect at the same height on the levelling staff. The instrument was then clamped, and the angle of inclination was read off on the vertical limb.

In one case, that in hand, the reading was 33° 10′, and the length AB was 165 feet.

Now observe that DB, which is the horizontal distance of B from A, is the line of the angle BAD; from the tables of natural lines take that due to the angle 33° 10′, which is equal to 0·5471; multiply this by 165 feet, which is made radius; the product, equal to 90·27 feet, is equal to the horizontal distance required, and to be plotted on the map for the point B.

Similarly the angle of depression to C was 45° 22′, and the length AC was equal to 210 feet; the natural line of 45° 22′ equal to 0·7116, multiplied by 210, equal to 149·436 feet, which gives the horizontal distance CE, also to be plotted on the plan.

The differences of level were not important to our work, but we ascertained these also as matters of interest.

AD is the difference of level between A and B, and also AD is the cosine of the angle DAB, being a perpendicular to the line DB, and intercepted between it and the centre A.

The natural cosine of the angle 33° 10′ is 0·8371, and multiplying this tabular number by 165 gives 138·12 feet, equal to AD, the difference of level.

Similarly, the natural cosine of 45° 22′ in the tables is 0·7026; multiply this by 210 feet, the inclined length from A to C; the product, equal to 147·546, is the difference of level between C and A. Nothing can be easier than this, and the use of the most ordinary tables of interest is not more simple. Of course we have not given these examples for the practised surveyor or the mathematician, but to induce the young surveyor to study the application of such simple trigonometrical calculations. We wish we could find a more simple expression, for we believe it would lead to a more extensive *practical* study of the subject.

CHAPTER III.

CHAIN-SURVEYING.

THE SURVEYS OF ESTATES, AND FOR ROADS AND RAILWAYS WITH THE CHAIN ONLY.

WE are not partial to the practice of making extensive surveys with chain only; it has, however, often to be done; and there is no reason why it should not be done with perfect accuracy; we only consider that it takes up more time and gives much more trouble than when the proper instruments are used.

We give an estate survey at fig. 17, made with the chain only.

It is always an advantage in such a case to have any old map or plan, however indifferent it may be, as it affords great assistance in the laying out of the chain lines; in this instance, however, it was not forthcoming; we had therefore to examine the ground well at first before laying out our lines, and the view in some instances was marred by a considerable growth of fine timber. The first thing to be done was to lay out our main lines through the estate and enclosures. We took the highest ground for our first point of examination; this was at about A.

There was a large tree in the distance, out of the estate, standing by itself, and in the direction of line I; we had therefore only to choose our point A for commencing at. In this we were guided by the object of getting a line on which we could obtain as much offsetting as possible right and left.

The point A being definitively chosen, with a view to lines right and left of A, we left a pole there, that we might be able to see the starting-point in our farther preliminary examination of the ground; in order, also, that in doing this we might have the direction of the line, we sent on a chainman to set up another pole at about half way on the line. Having directed the planting of this pole, we walked along the line, examining the side lines that would be required, with two objects in view—the offsets we should get upon them, and also there being good tie lines.

On getting at about the middle of the ground, where we could see to the right clear of the farm buildings and the orchard, and to the left clear of the wood, we looked out for another line, to go as much as possible through the centre of the estate. We should have liked to get nearer to the point A, but this would have involved running through the farm buildings and through the wood, which would have caused delay, and would not have given us more offsetting.

This led us to the left of the grounds, when we pretty well determined on line 4, at least approximately; we returned to the base, line 1, and determined the intersection of line 3 and line 1, because from this point we could get a good line 7, to take up the fence of the wood, give us a good station in the road, and from the end of which we could return to point A.

This being settled, we went up the road to the other end of the estate.

We here examined the position of line 2, with regard to its taking up offsetting; with regard to its commencement in connection with the end of line 1 and commencement of line 4, and with regard also to its termination and the commencement of line 3. Line 2 was then poled out, a pole left at the end of line 1, and we walked back down line 4, boning it out as we went along; determined the end of it in connection with line 5 and the point A.

Our main lines were thus all determined upon. The chain was cast out at A, and the chaining commenced from this point. The stations we left will all be seen by the intersection of other lines with line 1; they were almost all fully determined as we went along, so that there should be no after delay when we came to the side lines. Thus when we came to station 1,060 (see 'Field Book,' line 1), we determined the line 10, by setting up whites in the direction it was to run; and the same as regards line 9; in doing this we had regard to the road lines.

On coming to our main intersection of line 1, we looked out for the pole left at the end of line 2, and determined on station 2,770, line 1, with due regard to the production of line 3 into line 4. At 3,590 we left a station and white for line 15, and terminated line 1 at 5,060.

From the end of our base we turned acutely to the left, on for line 2 at once, it having been boned-out; settled about the little triangle to take the stream on the right of line 2; determined the station in the road at the apex of this triangle, so as to get a tie line, which should run down a portion of the road; and chained straight on to the end of line 2.

Before commencing line 3, and being at the end of the estate, we boned out line 15, with the assistance of the white we had left at station 3,590, line 1, and set out line 16.

We then chained line 3, left a station at 930, to run a line back to line 16 by the side of the stream; chained on to intersection 1,505 on line 15, on to 2,735, or 2,770, line 1, and to the end, taking the intersection 3,960 of line 4.

We then went back to the end of line 1, commenced chaining line 4, and chained on, leaving the necessary stations, until we reached our intersection of line 3. This gave us 2,700 on line 4, or 3,960 line 3. This closed our day's work.

In the evening we plotted the work as far as it had progressed. We will now say a few words about this.

The chain used on the survey was the 100 feet chain, and the work was plotted to a scale of 200 feet to the inch. The base line 1, being 5,060 feet long, the line on paper would be a little more than 25 inches long, or 25·3 inches. This is not a very long line, but some little care is required nevertheless in laying it down.

Plotting the Day's Work.—Lay your straight edge on the sheet of paper, which should be quite flat, and lay a weight at either end of the rule to keep it steady. Use a sharp-pointed pencil, and draw in a long straight line, by keeping the point of the pencil close against the edge of the rule, and by holding it perpendicular over the paper the whole way. This being done, take your scale, which will probably not be more than one foot long, and lay the zero at the point on the line which you have selected for station A, and with a needle-point prick off the first 24 chains, which will give the utmost length of your scale; now move the zero to the 24 chains, and repeat the operation; lastly, prick off the remaining 260 feet. Now lay your zero at the 5,060, and repeat the operation the other way, to test your work and the scale.

If you find all correct, you may now prick in your stations, from A, round each of which draw a little ring in pencil to distinguish them, and number them according to your chainage.

We have now to get in line 2; up to the terminal station it measures 3,450 feet, which is too great a length for any ordinary compasses; we must, therefore, have recourse to the beam compasses, by means of which we can describe arcs of any length, eight or ten feet for instance, if the beam is long enough.

In order to get the length of line within the beam compasses, lay off with the straight edge a line on the paper to answer the purpose of a long scale; on this prick off the length you require, in this instance 3,450 feet; take this distance within your beam compass, and from station 5,060 describe the arc of the circle for line 2.

We may now refer to station 2,770, line 1; up to which point, from line 2, the chainage was 2,735. Having laid this line off on the scale line above referred to, take it with the beam compasses, and from 2,770 describe an arc intersecting the former one. With the straight-edge, draw in lines 2 and 3, very carefully producing the last, as it intersects line 4. The lengths may now all be tested with scale, and line 3 produced to the length of 4,200 feet, making a station with needle-point at 3,960, where line 3 intersects line 4; from 3,960 draw a straight line to 5,060, the end of line 1, and see if with the scale it measures 2,700.

This is merely for the purpose of testing the day's work, because the triangle formed by lines 1, 4, and 5, should be laid down independently, in the same manner as the former triangle; the station 2,700 should then be pricked off on line 4, from the end of line 2; we should then carefully examine two things: the line from the end of line 2, drawn through intersection 2,770, line 1, to 2,700, line 4, should be perfectly straight, and the portion between these two stations should give exactly the length shown in the field book.

We believe enough has been said with regard to the work up to and inclusive of line 5. The triangle formed by part of line 1, and lines 6 and 7, shows plainly that it was laid out to take up the fences; this triangle was tested by line 9, which was carried on to line 5. Line 8, along the road, was run from a station on line 6, into a station on line 9; and this line would be laid on paper in the same manner. Similarly the next line in the road was run from the end of line 8 on to a station on line 7; the next from the end of the last line on to a station on the road on line 3. Line 13 was run from a station on line 9 on to a station on line 4, the intersection with line 3 being taken, and a station left for running line 14 into a station on line 1.

We have referred to all these lines to show that they are to be plotted on paper by the same means they are set out and chained in the field; that is, by drawing straight lines from, and to given points on the paper, and which are given by the fact that they are pricked off on given lines.

In the course of the preceding observations, we have referred to the scale line laid down on the paper. It is to be noted that paper almost always contracts very much in the course of time. It is also very liable to be affected by atmospheric influence, and, on different days, long lines measured with the scale may be of very different lengths. But if we have a scale on the same paper, it will contract and expand with the other lines laid down on the plan.

For these reasons, the plots of extensive surveys should always have a scale laid down on them from the beginning of the work, and where great accuracy is required, there should be two different lines with the same scale upon them, one at the foot of the plan, along the breadth, and the other up the *length* of the paper, the contractions in these directions being sometimes unequal. Let it be understood that we are now referring to surveys, where accuracy is of importance.

Scales are liable to be affected by the same influences, and in the same manner; that is, expansion and contraction, but boxwood less than ivory.

A matter, however, of even greater importance, is the elongation which surveying chains are liable to from hard work; they have been known to be as much as three and four links too long.

The chain should, therefore, be often tested; new chains almost every day, when hard work is going on, and compared with a standard chain; in disputed cases, this latter chain is sometimes made use of instead of the ordinary one.

But to return to our every day work; when the surveyor reaches his quarters, before commencing his work, he should cast out the chain on a piece of level ground, stretch it straight and drive in a couple of stumps at the chain length, nearly flush with the ground; then drive a strong nail into one of them; over this pass one handle of the chain; pull tight over the other stump, and drive in a nail, at the chain end, into the other stump. This will give a standard with which the length of the chain, if new, should be compared every day, and always at least every two or three days. When it is found to have lengthened, the elongation should be measured, and the chain should be taken to the nearest smith to be shortened in the presence of the surveyor himself; otherwise one or two of the rings uniting the links may be taken off.

We have here supposed that the chain when first about to be used, is *known* to be of the correct length; if this has not been previously ascertained, we must obtain our standard by different means.

Drive in a couple of stakes some distance apart, more than a chain length, and strain a cord tight between them; from one end, where a nail has been driven in, set out along the length of the cord the length of a chain; this may be done with a ten feet rod, or a tape if you are sure of its length; we prefer the former; measure the length over again, to be sure it is correct, and drive in the other stump, and the nail at the end of the exact chain's length, as measured with the rod. There should, in fact, be two such rods, placed end to end, the first being moved on when the second has been laid. In ordinary cases we may dispense with one of them, by driving the point of a knife at the end of every length as the rod is laid.

Railway and Road Surveying with the Chain only.—For this work our operations are similar to those above described, but we have only a long strip, instead of great breadth as well as length, generally not more than ten chains (Gunter's) on each side of the centre line; unless, in very particular cases, the work is not done with that minute care which we should bestow on surveys for the transfer of property. We are now referring to Parliamentary or *quasi*-Parliamentary work.

Very often, indeed, these surveys are merely approximations to accuracy, and sometimes even there is a considerable amount of guesswork about them. The student must bring himself by practice to understand how far he may venture in exchanging rapidity for accuracy; it is very certain that the description of work we have been describing above would not give the satisfactory amount of chaining for a day's work, for Parliamentary work.

In fig. 20 we give an example of railway surveying, where we shall endeavour to explain, as clearly as possible, how the work is carried on, quickly and with sufficient accuracy for the purposes required.

In the first place, we shall suppose that we are working at home, which differs very widely from the surveying operations which the engineer has to carry on abroad; at least, in most countries to which the English surveyor is sent. We will further suppose at first that we are working without any other guide than the Ordnance map.

This map is to a scale of one inch to the mile, and shows roads, railways, rivers, canal streams, buildings, hilly ground, and all leading features, but none of the details of the properties to be traversed in the course of the survey. Consequently, the surveyor has only these features to guide him in selecting his chain lines, and it is only after a little practice that he becomes acquainted with all the value of this map as a guide.

The portion of Ordnance map handed to the surveyor shows the general route, generally marked in red, and laid down by the engineer in charge of the proposed works. This and the above-mentioned features, roads, streams, &c.,

must guide him over the country in laying down his chain lines. The student will do well to familiarise himself, not only with the Ordnance map itself, but also with the way it is to be used in the field; this he may readily do by always taking about with him in the country the Ordnance map of his district; by frequently consulting it he will become acquainted with the manner of using it, not only for ordinary purposes, but for those we have now in hand.

We must now suppose him to have reached his quarters, and to be supplied with so much of the map as contains the work confided to him; to have engaged his chainmen and to be starting for his first day's work.

One of the great advantages of the Ordnance survey is, that every little block of buildings, even small farms, have a name attached to them; unfortunately, however, the people about the country do not generally know it, and it sometimes takes some time to get a fair start; that is, to be able to say, 'There is "so and so" farm or mansion, and my work passes within a few chains of it;' but having once got a starting point, it is very easy to connect other buildings along the line with those shown on the map.

In our example there is a little block of buildings at N, which will at once be a guide, also the fork in the road; the road runs down towards the sudden bend of the railway line from the buildings, to a sharp skew crossing of the road, at a certain distance from the fork of the roads.

These are quite sufficient to get a fair start on the field-work; now for laying out the chain lines. We see by fig. 20 that we can get on to the ground by two roads; in choosing the end at which to commence our laying out, we shall probably be guided by the selection of high ground, from which we can get a view of the country right and left.

We had high ground at B, in fig. 20, from which we could see forward in both directions. The Ordnance map was held so as to lay north and south, and then, looking over the country towards A, we caught sight of a tree at a distance; and although a line from A to B is rather off the works, we took it as a first base, because the whole of the ground had to be surveyed.

The chain and some of the poles had been sent on to A, or we should have commenced work at once at B, but we took advantage of being on the spot to set out some side lines, E D C, to look at the work beyond B and Q, where the works were to take a sharp reverse curve, to set out the line O G as we went along towards the point A, the exact position of which was ruled by the line J A. With three poles and a few whites the whole of the work was set out, and a pole left at A; the chain was cast out, and we chained on for B, leaving the required stations for running the side lines, and these stations were marked with whites, not only in order that they should be readily found when wanted, but also that we might be able to chain to them when required, without the trouble of setting up poles, which involves running backwards and forwards, and much loss of time; for short lines out of bases, and for this kind of work, we always sight upon a tree or bush.

On reaching the wood, we set out the little rectangle *abcd*, just sufficient to clear it, and booked the whole figure in our field book; we then chained right away for B, and a little beyond. We may now observe that the offsets were all paced, instead of being measured with the offset staff, and much of the minute accuracy required in the former survey was in this case overlooked.

It will be unnecessary to say anything of the work now behind us on the base A B; the lines shown in the figure explain the work done; it was all done by triangles out of the base, and what we have said with regard to fig. 17 fully explains the method in which the chaining was carried out in fig. 20. On reaching, however, the ground between K and B, the direction of the base work required to be changed, on account of the curves on the proposed line of works.

For this purpose the line O B Q was laid and K Q, both being produced as far as required, when other lines were again thrown up, to follow the general line of works; in carrying this out we have to keep in view lines which will take up the offsetting and check the work, as for instance the line E D C, so as to include all the fences, &c., within ten chains on each side of the centre line on the Ordnance map. One most important object is that nothing on the ground shall be omitted from the map, that is in the shape of enclosure, building or road.

We now come to the case of road and railway surveying, where we make use of some existing map, generally a portion of the parish map.

When the surveyor is not supplied with a tracing of this, he will have to take it himself from the parish map, which he can always obtain, from the clerk of the parish, by paying him a slight fee.

On this map, as far as it extends, the surveyor traces out the general direction of the line given on the Ordnance map, and takes a tracing some ten or twelve chains wide on each side of the centre line, paying particular notice to the parish boundaries.

The centre line of works may then be roughly shown on the tracing, and he can then very easily see on the grounds whereabouts the proposed works are to be.

He lays out his base line accordingly, chains and picks up the offsetting for some four or five chains on each side; at the same time he compares his tracing with the ground, to see what alterations may have occurred; as, for instance, fences grubbed up and new ones raised; changes in roads, new buildings, &c., &c.

Often it is only when the direction of the base line is changed that more lines than one will be required; the extra lines being required to fix the change of direction.

To get the remainder of the work on paper, after the whole of the field work has been plotted, the tracing from the parish map is laid down on the plotted field work, so as to make the new work and the old coincide as nearly as possible; generally speaking, it will be found that the parish map has considerably contracted, sometimes enormously so. In this case we must fit a piece at a time of the old work on to the new, and prick through, from the tracing on to the plan, the fences we have not included in our field work, taking care that all alterations are carefully attended to on the new plan.

Of course the reader will have understood that all these alterations, when they have occurred, are duly shown on the tracing, by the surveyor, whilst he is in the field.

If in pricking through, in the above-mentioned manner, the fences from the parish tracing on to the plan, we are careful to prick lightly, and only at about the sixteenth of an inch apart, there will be no difficulty in tracing the needle points on the paper, and thus getting in the fences, roads, streams, buildings, &c., which have not been included in our field work. The reader will observe that this is by no means difficult; but it requires care and a little practice, particularly to do it at the rate required during the preparatory parliamentary session.

It is a habit which, however, may be very easily acquired, because it may be practised at any time by the young man who is anxious to acquire the routine habits of field and office practice.

Having, however, got in a portion of his work, perhaps a quarter of a mile, or even ten chains, the surveyor shifts his tracing forwards, so as to make another portion fit, and he repeats the whole of that which we have pointed out above.

Very often, however, it happens that the parish survey has been plotted to a different scale to that which we are using; in which case the parish tracing will have to be reduced to the proper scale. It is, therefore, very important, when taking the tracing from the map, to trace off also the scale. Where a line runs for a mile or two through one parish, it is worth while to do this work with some little amount of care:—we will not venture to say great care, because, undoubtedly, 'sharp work, near enough,' is the great thing required in parliamentary work; the important thing to learn is to be neither fastidious nor careless.

The ordinary parliamentary scale, for some years past, has been six chains to the inch, so that a quarter chain, 17½ feet, is represented by only the twenty-fourth part of an inch.

It is due, however, to the student to observe, that this kind of work has sometimes to go through an extra severe ordeal under 'standing orders.' We knew a case, some years ago, where a scheme met with a very determined opposition, and where the opponents had every inch of the ground gone over *carefully* surveyed. In such cases, where parliamentary plans have been prepared entirely in the above manner, that is with one base line and parish plans, unsound work becomes very apparent, if the parish surveys happen to be bad, which is not a rare occurrence.

However lenient the Examiner may be disposed to be, in view of a violent opposition, the array of allegations is formidable.

We have now noticed both sides of the question, and the student must learn to acquire habits that will suit different demands in his work; he must try and learn to be 'near enough,' and yet not careless.

To one who is determined to learn, we would say, after all we have now written on the subject of Elementary Surveying, take a chain and poles, and go and survey a mile of fields, as for parliamentary purposes; do it steadily and carefully at first. Let this be plotted.

He may then survey this mile over again, but laying out different chain lines, and bind himself to do it in half the time; let him make a plot of this also, and a tracing of it, which he may lay on plot No. 1. He will then see how far he may venture in producing rapid work.

CHAPTER IV.

SURVEYING INSTRUMENTS.

THE CROSS STAFF; OPTICAL SQUARE; PRISMATIC COMPASS; COMPASS SURVEYING; CIRCUMFERENTER; BOX SEXTANT; VERNIERS; THEODOLITES (CRADLE TRANSIT AND EVEREST); HADLEY'S SEXTANT.

The Cross Staff is a very simple but rather old-fashioned little instrument. It is principally used for setting out right angles on the ground, which it does very accurately; and in mere chain surveys it is undoubtedly very convenient for setting out lines of any moderate length perfectly square to a base line; when these lines, however, are not made too long, and in very sloping ground, where the eye only is very apt to deceive the observer.

If the instrument has been well made, and is of any moderate size, it may be used advantageously in boning a line through a wood; and also in setting out short bases, if no better instrument is at hand, more particularly in crossing any high ground with a sharp ridge, where two observers sighting each other on back and forward objects would only have a very short range of country between them.

The instrument consists of a hollow cylinder, with sights very correctly set by the maker at right angles to each other; when the instrument is used, it is set on the top of a staff, which is thrust into the ground exactly at the station; it is then turned round until, through a pair of sights in line with each other, the observer can see an object in the distance in line with the vertical wire. If there be a forward object which he can see also, he may then go to the opposite side of the instrument and again look through, *when, without touching the instrument*, he should see the forward object also in line with the wire; if the wire does not intersect the object, then he is not exactly on the line; but if the intersection is correct, and he now wishes to set out a line at right angles to this base, he makes use of the other pair of sights; to do this, he has only to send a chainman forward, with a pole or with a white, who, according to the directions he will receive from the observer at the instrument, is to set up his pole or white, and which will then be on a perpendicular.

Some cross staves are made with sights, intersecting at angles of 45°, as well as at 90°; these may of course be used in the same manner for setting out lines at such angles; and to the surveyor who generally makes use of the chain only, that is, without the assistance of the theodolite, this cross staff is very often of considerable use.

THE OPTICAL SQUARE.

The optical square is a little reflecting instrument, also for setting out right angles, or for finding where a perpendicular from a given object will fall on a given base.

In flat level country the optical square is a very superior instrument to the cross staff.

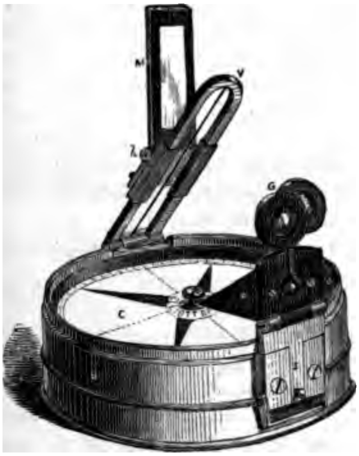
This instrument consists of a round shallow box provided with two mirrors, which are set so as to reflect an angle of 90°. In setting out a right angle with this little instrument, the observer stands at his station, looks through the unsilvered portion of glass to see a forward object, when the object which is reflected in the silvered portion of the glass, and corresponds also with the object seen by direct vision, is at right angles. Similarly, if we want to drop a perpendicular from a given object to a given line, we have only to walk along the base until the object at one end of the base, and that just referred to, are both seen coinciding, by direct vision and by reflection.

THE PRISMATIC COMPASS.

In the prismatic compass, a triangular glass prism is substituted for one of the sights of the ordinary compass; this prism has the advantage that it can be seen through, so that a sight can be obtained at the same time that it reflects the degrees on the floating card immediately under it; that is, the sight and the reading are obtained at the moment of coincidence.

In the figure, B is the compass box, and C the floating card, which, being attached to the magnetic needle, moves with it, round the agate centre, on which it is suspended. The circumference of the card is usually divided to a quarter or half degree; unless, however, with a large-sized instrument, we seldom attempt to read nearer than half a degree, unless indeed in very clear and calm weather.

P is the prism through which the surveyor observes. The perpendicular wire of the sight vane, V, and the divisions on the card, appear together on looking through the prism; that particular division on the card, with which the wire coincides, when the needle is at rest, is the '*bearing*,' of whatever object the thread or wire may bisect; it is, in fact, the angle which the line of sight makes with the direction of the needle.



The fine vertical wire in the sight vane is brought to bisect any object of which the bearing is required by turning the box round horizontally. M is a mirror made to slide on or off the sight vane; it can be made to face upwards or downwards, or inclined at any angle by means of a joint, with which it is supplied for the purpose; unless moved intentionally, it remains stationary by the friction of the slides.

The object of this mirror is to reflect any object which is at a much different level to the ground on which the observer may be standing. The coloured glasses G are made use of when the rays of the sun interfere.

The instrument is provided with a spring for checking the vibrations of the card; when observing, if this spring is pressed by the finger and then released, it brings the card more readily to rest. A stop is also provided to throw the needle off its centre. The use of it requires particular attention, as otherwise the sensitiveness and accuracy of the instrument would soon be irretrievably injured.

In making use of the instrument, you first raise the prism in its socket S, until you obtain a clear vision of the divisions on the card. Then standing over the station where your angles are to be taken, you hold the instrument to the eye and look through a slit, turning round until the sight vane wire V intersects the first object of which you wish to obtain the bearing. You then touch the spring, which gradually brings the needle to rest, and the reading of the division on the card, which coincides with the sight vane wire, will be the magnetic bearing of the object you have been looking at.

If you repeat this operation with any other object the difference between the bearing of this object and the bearing of the former one, will be the angular distance between the two objects. Thus, if one reads 50 and the other 10, both east or west, from north to south, the angle will be 40°.

The figures on the compass card are reversed and written upside down, or should be so, because they are reversed by the prism.

This instrument is very convenient for rapid survey, that is, where great accuracy is not required, but only in calm weather; the reading of the card when there is much wind is almost impracticable. A flat stand, on which to rest the prismatic compass when taking bearings, is a great advantage; by means of this stand, in moderately fine weather, a good deal of execution may be done with this little instrument, after one has become used to manage the vibrations of the compass card. The offset staff may easily be made to answer this purpose.

In some instruments the card is numbered round by east to south 180°, and from south round by west to north 180°; this rather simplifies the readings, for we know that if we have a reading, say 35° north-east, then it will be 35° south-west. With such instruments it is understood that all readings going east read from north to south, and that all readings west, go from south to north.

COMPASS SURVEYING.

At the same time, we must say that we do not recommend the use of instruments differing much from those generally employed in the profession. Engineering surveyors have to work so much together and have so often to connect their surveys by observation, that the use of instruments differing in their manner of being used leads to confusion.

We give an example of compass surveying at fig. 22, and of the manner it is generally plotted with a paper protractor:—

Let the first reading 1 and 2 be 40° 30′ North East.
„ second „ 2 and 3 be 31 0 North West.
„ third „ 3 and 4 be 57 30 North East.
„ fourth „ 4 and 5 be 50 30 North West.
„ fifth „ 5 and 6 be 7 0 North West.
„ sixth „ 6 and 7 be 5 30 North East.
„ seventh „ 7 and 8 be 38 30 North East.
„ eighth „ 8 and 9 be 72 0 North East.
„ ninth „ 9 and 10 be 62 30 North East.

To Plot the above Bearings.—On the sheet of paper on which you are going to plot draw a long straight vertical to represent the magnetic north and south points; at right angles to this draw another long straight line to represent the west and east points.

It is evident that we may draw or describe any number of parallels to the above two lines, and that these parallels will bear, the one north and south, and the other west and east.

Let the first intersection we have referred to be considered the starting-point on our survey: that which we have generally called A.

Take the card-board protractor to which we have referred; lay it on the paper, and make the centre of it coincide exactly with the point of intersection (A), and so that zero and 360 shall coincide with the north point, and zero and 180 with the south; and let 90 be made to coincide with the east, and 270 with the west; which will be the case if the lines are at right angles with each other.

Lay some heavy weight on the protractor, that it may not be disturbed. Now with a needle-point prick through on the paper the three following points:—

1 and 2	40°	30′	North East.
2 and 3	31	0	North West.
3 and 4	57	30	North East.

Without disturbing the protractor, prick off the same angles, but at the south end. Thus:—

1 and 2	40°	30′	South West.
2 and 3	31	0	South East.
3 and 4	57	30	South West.

Remove the protractor, and draw straight lines through 1 and 2, 2 and 3, and through 3 and 4; if the work has been correctly done all these lines will pass exactly through the centre.

On the first line, 1 and 2, starting from A, plot off to scale the length of your first chain line; set your parallels on 2 and 3, and run them up to the termination of the first line; draw a straight line along your parallel through this point, which will protract the bearing of 2 and 3; set off the length of this second chain line with the scale on the bearing last found.

Now set your parallels to 3 and 4, and run them up to the end of the line last plotted; draw in a line along the parallels through this last point which gives the bearing of your third, on which you have now only to lay off the distance with your scale.

This carries us beyond a convenient range of our first magnetic. Now through the point last found draw a parallel to our first vertical line, and through the same point a line at right angles to it, exactly as we did in the first case, and lay down the protractor in the same manner; that is, zero and 360 to the north point, and zero and 180 to the south; 90 to the east, and 90 and 270 to the west.

Prick off:—

4 and 5	50° 30′	North West.
5 and 6	7 0	North West.
6 and 7	5 30	North East.

Taking, again, every care that the protractor remains undisturbed; prick off the same angles, but at the south end. Thus:—

4 and 5	50° 30′	South East.
5 and 6	7 0	South East.
6 and 7	5 30	South West.

Take up the protractor and draw in the straight lines 4 and 5, 5 and 6, 6 and 7, which should all pass through the centre—that is, the termination of line No. 3; from this point on line 4 and 5 prick off with the scale the length of line 4 and 5 from the field notes; proceed with the other lines exactly in the same manner.

Fig. 22 is plotted from field notes over nearly seven miles, so that it will be seen that the plot is only in miniature.

Our card-board protractor is one foot in diameter, and is divided to ten minutes, and the figures range, as shown in fig. 23. It will be perceived that this is a most convenient form for plotting such surveys, and that the size and graduations of the protractor enable us to obtain all the accuracy which is generally required from mere compass surveys, which is a very rapid way of getting over the ground, where there are not many important details to fill in; such as many, we do not say all, of the surveys we have to prepare in foreign lands.

When the system is applied with care, it is often very useful for home surveys, when dispatch is the primary consideration.

THE CIRCUMFERENTER.

This very useful instrument, particularly for all purposes of compass surveying, may be considered to hold a rank between the theodolite and the prismatic compass.

We do not consider it quite so accurate as the theodolite, but it is undoubtedly a most convenient instrument, and useful surveys may be produced with it.

The compass does not point with sufficient precision to the division indicated; the point of the needle has considerable thickness, and does not come in contact with the circle.

It does not point to the same point in the horizontal circle, even during the same day, the direction changing to the extent of nearly a quarter of a degree between sunrise and noon. The great defect, however, of all compass instruments is their liability to local attraction, and the more sensitive the magnet the more liable it is to this attraction. The diurnal variation in our hemisphere is from ten to fifteen minutes west, from 8 in the morning till 2 in the afternoon, when it gradually returns to its position. In the Southern Hemisphere the variation is so many minutes east.

This variation will give a difference of 23 feet at the end of a mile, not in length but in position; the time at which important bearings are taken should therefore be noted.

In compass instruments, short shear steel needles, about 4 or 5 inches, not more, in the form of a rhomboid, and cleared out in the middle, are the best; and in good instruments it may be noted that the needle vibrates a long time before coming to rest.

It is important to observe that in this instrument, as in the prismatic compass, the needle should be raised off its pivot when not in use; there is a special provision for this with every instrument, but it is not made use of so often as it should.

The circumferenter is provided with a pair of sights; these consist of upright bars of brass, with openings in them of various forms, and 'pin-holes,' so that considerable accuracy may be obtained as regards the clear vision, and at the same time over a great range of level.

The pivot and needle are sunk in a circular box, the circumference of which is divided into degrees and half degrees. The pair of sights with which angles are taken usually carry verniers to read off minutes on the graduated circumference. The instrument is provided with the necessary levels to enable the observer to set it up level when he is about to take an observation.

To take a bearing, set up the instrument over your station by means of the plummet hanging from the centre, and level it, which you will easily do by bringing the bubbles of the spirit levels to the centre of their runs.

Turn the sight in the direction of the object of which you require to take a bearing, and look through one of the small apertures; move the sights until you see through the little aperture that the wire at the other end of the sight coincides with the distant object. During this time the needle will probably have come to rest, and the division in the circumference pointed to by the line of sight is the bearing, north or south, according as the former or the latter is farthest from you on the circle.

Without disturbing the instrument, you may now read off also the angle of bearing at the other side.

In many instruments two cardinal points of the compass are reversed; that is, east is on the left hand and west on the right, which is inverting the usual order of things. The following lucid explanation of this is given by an eminent American writer:

'We can now understand why W is on the right hand of the compass box and E on the left. Let the direction from the centre of the compass to the point B in fig. 25 be required, and suppose the sights in the first place to be pointing in the direction of the needle SN, and the north sight to be ahead.

'When the sights and the circle to which they are fastened have been turned so as to point in the direction of B, the point of the circle marked E will have come round to the north end of the needle (*since the needle remains immovable*), and the reading will therefore be east, as it should be. The effect on the reading is the same as if the needle had moved to the left, the same quantity which the sights have moved to the right, and the left side is therefore properly marked east, and *vice versâ*. So, too, if the bearing of the line to C be desired, half-way between north and east, *i.e.* N. 45° E., when the sights and the circles have turned 45° to the right, the needle really standing still, has apparently arrived at the point half-way between N. and E., *i.e.* N. 45° E.'

THE BOX SEXTANT.

This is one of the most useful instruments the surveyor can possess, and we never think of going into the field without having this little instrument about us.

After many years' experience, we venture to say that there are very few difficulties which can occur in practice which may not be got over by the use of the sextant. We refer, however, more particularly to that made after the 'Ordnance' pattern, and which certainly, as we shall be able to prove in the following pages, is very superior to the box sextant ordinarily sold. Many makers have of late years left off making the box sextant after this particular pattern; and this we believe has been occasioned by only a few surveyors knowing how to take advantage of its superior construction when it was first introduced.

The principles of its construction are as follow, always remembering, however, that the box itself is not here described:

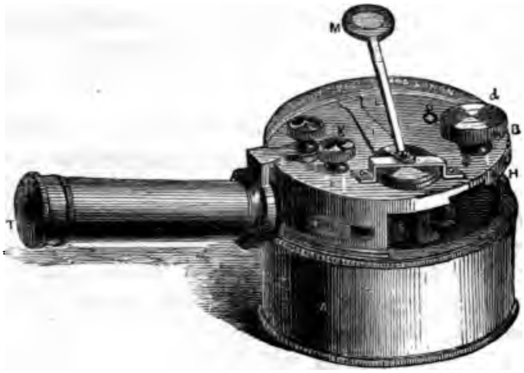
Let O B C (fig. 26) represent a sextant, having an index O G moveable about O as a centre. This index denotes the angle which the index has travelled over on the arc B C, when the angular distance between two objects has been measured. H S is the half-silvered horizon glass, fixed parallel to O C.

Any ray of light L O, impinging against the mirror O, is reflected off at an equal angle to the horizon glass at M, whence it is reflected to N, when the eye likewise receives through the transparent part of that glass a direct ray from the horizon. It is to be distinctly understood in this description that one half of the horizon glass is silvered and the other half unsilvered, so that one object is seen through it by direct vision and the other object by reflection in the silvered half.

The reflected angle B O G equal to the incident angle L O I; the reflected angle H M E equal to the incident angle S M O; the angle M O E equal to M E O, because H S is parallel to O C; and the angle L O N equal to twice the angle of inclination of the two mirrors—that is M G O.

Hence the arc on the limb B C, although only 60°, is divided as if it were 120°.

The above is the principle of construction of the box sextant, which is represented in the annexed figure.



I is the index, to which motion is given by the hand, but much better by a rack and pinion motion, concealed within the box and turned by the milled head, B. A far better motion is given by a tangent screw in the Ordnance pattern box sextant.

The glasses shown at G and H are within the box, by which they are protected from injury, and their adjustments, when once perfected, are protected from any disturbance, so much so that they can only be deranged by intention.

The horizon glass H, alone has a contrivance for adjustment, both to set it perpendicular to the plane of the instrument and to correct the index error, which had better be kept correct, as it is not likely to get out of order. The key at K fits at both places to accomplish this. We advise the inexperienced not to meddle with it; no adjusting is required when the instrument is turned out of a respectable maker's hands. If it should be found to require adjustment, it should be returned to him.

We may at once observe that the telescope, T, is useless, and may be cast aside by loosening the milled head which holds the shoulder-piece. There is a little slide, shown in the figure just above A, the box, which is to be pushed over the opening made for the telescope; in this slide is a pin-hole, by means of which a plain sight may be taken.

There are two dark glasses within the box to protect the eye, when observing, from the direct or reflected rays of the sun.

When the instrument is not in use it is kept, reversed, in the box A, which protects it from all violence. It may be thus carried about in the pocket anywhere; it would be better carried in a sling case, if the makers would only make this appendage to open more conveniently, one great advantage of the box sextant being the readiness with which it may be used. It is, beyond all others, a handy instrument and a most accurate one, if properly made and properly used.

When about to be used, the box sextant proper is unscrewed from its box A, reversed and screwed in again, when the box constitutes a handle to hold it; before doing this, however, the dark glasses require to be pushed back through a slide in the under part of the instrument, to remain out of the way in the box; this is, of course, when they are not required to look at any object, the sight of which may be obstructed by the rays of the sun.

To measure an angle subtended by any two objects on a horizontal plane, the instrument is held by the box in the left hand. The eye is then applied to the pin-hole above referred to, when it will see one of the objects before it through the unsilvered portion of the horizon glass; this obtained, the index is turned by means of the milled head, B; after a few turns, sight will be obtained of the other object in some part of the silvered part of the horizon glass; it is received reflected there from the index glass, which has been made to rotate on its axis towards this second object; by continuing the motion of the milled head the two objects are made exactly to coincide, one over the other, in one vertical line, if the objects are in one horizontal plane.

For instance, let us suppose that one of our objects is a surveying pole, with a red and white flag over it, and that the other on the right hand is the corner of a house; when the angle has been accurately measured by the index, the corner of the house will be seen exactly over the pole, the flag of which will be then obscured. We have now only to read off the angle by means of the *vernier*, which we will presently explain.

We have now to explain how we may ascertain if one of the most important adjustments is correct in the construction of the instrument.

Bring the broad arrow of the index, by means of the milled head, B, to coincide exactly with zero on the limb; this you can do to the greatest perfection by looking through the magnifier, M; take care this is thoroughly well done. Now look through the pin-hole at the angle of some building or some tall straight flag-pole—if half a mile off, all the better—and see if this angle of a building or the pole forms exactly one line in the silvered and unsilvered portions of the horizon glass; if it is so, the adjustment is good; if otherwise, the instrument requires correction.

Supposing that the coincidence is not perfect, move the index by the milled head, and then read off on the limb how much the broad arrow has deviated from the zero. By means of the key, K, this error should be corrected by applying it to the key-hole and turning it until the coincidence is perfect, *when* the broad arrow of the index coincides exactly with the zero on the limb.

From what we have now observed, it will be seen that any one purchasing a box sextant may test the instrument by observing from the shop door of the maker to any distant corner of a building. It is, however, very rarely that a respectable maker turns out an instrument out of adjustment.

A more perfect method of testing the accuracy of adjustment in the sextant, though seldom applied to the box instrument now described, is the following: by observing on the disc of the sun.

For this purpose the dark glass is brought before the eye end of the pin-hole. The observer then looks directly at the sun, and moves the index a little backwards and forwards of zero; the sun's *reflected* image will be seen to pass directly over the disc, as seen directly through the *unsilvered* portion of the horizon glass; if in this passage the *reflected* completely covers the *direct* image, the horizon glass is perpendicular to the plane of the instrument, and needs no correction; if otherwise, we must apply the key, K, to the key-hole in the *top* of the box, until this adjustment is perfect.

We may then try the other adjustment, by bringing the *reflected* image of the sun's lower limb in exact contact with that of the upper limb, as seen through the unsilvered portion of the horizon glass: take the reading of the vernier; now move the broad arrow of the vernier *back*, beyond the zero of the limb, until the reflected image of the upper limb is in exact contact with the lower limb, as seen through the unsilvered portion of the horizon glass. Take off the reading on the small portion of the limb beyond zero, *called* the arc of excess; if this equals the former reading, this also is in adjustment. If otherwise, half the difference of the readings constitutes the *index error*, which will be constant for all angles taken, if not corrected; *plus*, if the first reading be in excess, and *minus* if the second reading is the greatest.

The correction for this adjustment is made by applying the key, K, to the key-hole at the side of the box, and turning it until each of the above readings is equal to half the sum of the two readings first taken.

When this has been perfected, the broad arrow of the vernier should be made to coincide with the zero on the limb; it should then be seen whether the direct and reflected images of the sun form one perfect orb; if they do not, the above adjustments should be further examined, as whilst we are doing this work, it may as well be made perfect once for all.

We do not, however, advise this trial being made, before the observer has made himself pretty well master of the principle of his instrument, and become accustomed to handle it with ease. Before attempting it, he should have made himself familiar with all the details of its construction, and with the reading of the index on the limb to a considerable degree of accuracy. This he will best accomplish by standing at an open window, and leisurely taking numerous observations on any surrounding objects; having taken these angles and noted them down, he should repeat them, and see how the second series agrees with the first.

We have used the box sextant for some twenty-five years on every description of land and marine survey, and we feel confident in recommending it to the use of the young surveyor, and in advising him to make himself practically and thoroughly acquainted with it. We have already described one way of using it, and we may now add that the farther the objects to be observed are from the surveyor, the more accurate will be the observations. Where one is very near, and the other very distant, better results are obtained by seeing the near one, directly, that is through the unsilvered part of the horizon glass, and the other, or more distant object, by reflection. This, however, only relates to where great accuracy is required, for otherwise the difference is quite immaterial.

Again, for very accurate observations, the two objects observed should be quite or very nearly on the same horizontal plane; we do not always find this to be the case in practice; one object is often very much above the other: when this is the case, there will be a corresponding error in the observation, because instead of holding the instrument level, we are obliged to hold it in a plane slanting to the horizon. The error, however, will not be so great as to cause any uneasiness, unless there be really a great difference of level for short distances; when this is the case, it is best to set up a pole at a more convenient level, and exactly in line with one of the objects.

In the box sextant made after the Ordnance pattern, which, as already observed, is very superior to the ordinary instrument, motion is given to the index by a tangent screw.

But besides this, the divided limb is numbered both to the right and left, commencing at zero to 120°, and backward from 120° to 180°, and beyond to 230°; the latter row of figures is farthest from the divisions, and belongs to the supplementary angles; their zero division of the vernier is at the end, contrary to that of the angles reading from zero to 120°.

Beneath the index glass is fixed a similar one, in such a manner as always to reflect the image of an object to the eye, when applied to a hole in the side of the box near the division 120°, at the constant angle of 90°; whence the observer must direct his sight towards the right hand, and at right angles to the real place of the object.

When the index is set to 180°, its glass will also reflect an opposite image to the eye at right angles to the left hand (the two glasses being then exactly across each other): consequently, an eye looking through the hole near the division 120°, will perceive objects 180° apart, to coincide at right angles to a line connecting them. Thus a point can be found in line between two stations. The observer, with the instrument set as above described, having placed himself as nearly in line as he can approximate, must apply his eye to the hole near 120°, and looking at right angles to his chain line, step backwards and forwards, until he finds the two distant objects on his chain line to coincide; he will then stand on a point in line between the two distant objects. To verify this he should then turn himself half round, and looking in the opposite direction, see if the objects still coincide, which they will do if they are not much out of level with each other. If he finds he has to move to make them so, then he should mark the difference, and this halved will give him the true point required.

The adjustment of this part, as well as the method of observing supplemental angles with it, is performed in the following manner: Choose two objects in the horizon, the farther apart the better, but not nearer than 140°; turn your face at right angles to the right hand object, so as to get sight of its image in the fixed glass; then, by moving the index, bring the image of the other object, seen by reflection in the index glass, to coincide exactly with it on the line of separation of the two glasses. Read off the angle, turn half round, and take in like manner the angle which the same objects make the other way.

It is evident that the sum of the two angles should be equal to 360°, and also, that if they exceed that quantity, half the excess must be subtracted, and if they fall short of it, half the difference must be added, to obtain the true angle.

The error, if any, may be corrected by applying the key above referred to, at the key-hole underneath the box.

The instrument above described has also been made with the addition of two spirit levels, fixed at the back of the horizon glass, at right angles to each other, so that standing before the object, you look perpendicularly down the plain sight, and moving the index, bring the image of the objects to appear with the small bubbles of the levels, when in the centre of their runs. The reading of the instrument will then show the supplement of the zenith distance, and its complement to 90° will be the angle required; elevation if more than 90°, and depression if less. This obviates the necessity for an artificial horizon, and merely requires a little practice with the instrument.

VERNIERS.

The *vernier* is a contrivance for estimating subdivisions of the graduations on the *limb* of any instrument. It is applied to sextants, theodolites, and some circumferenters.

It is a scale whose length is equal to a certain number of parts of that to be subdivided, and depends on the degree of minuteness to which the subdivision of the graduations of the limb is to be carried. However this may be, it is divided into parts, which in number are one more or less than those of the limb taken for the length of the vernier.

If it be required to measure to hundredths of an inch the parts of a scale which is graduated to tenths, it may be done by means of a scale whose length is nine-tenths of an inch, and divided into ten equal parts; or by one whose length is eleven-tenths of an inch, and also divided into ten equal parts. In either case the difference between the divisions of the scale and those on the primary scale is the hundredth of an inch.

Such a scale made to move along the edge of that to be subdivided, is termed a vernier. We must now explain how, by this means, the subdivisions of graduated limbs are estimated.

For this purpose we may take the method of estimating the subdivisions of the sextant as one which will explain the method of reading off any other instrument.

In figs. 27, 28, 29, and 30, some of the divisional lines on the limb of the instrument are longer than others, and are numbered at every fifth. The spaces between these lines are to be read as representing *degrees* of the circle; they are subdivided by smaller lines, and the smaller space represents minutes.

If the degrees are divided into four by three of the shorter lines, each of the subdivisions will represent the fourth of a degree, or 15 minutes; if there be six parts, there will be five of the short lines, each of which will denote 10 minutes, reckoned from the commencement of the subdivisions.

Similarly, some of the divisions on the vernier are marked by longer lines than others; these indicate single minutes, as on the limb the longer divisions indicate single degrees. The divisions are numbered from right to left; the extreme right one is zero, and is denoted by a zero, a broad arrow, or a diamond; the shorter divisions on the vernier show seconds, as the shorter divisions on the limb showed minutes.

If the spaces between each minute are divided into four, each of the dividing lines will denote 15 seconds, and if into six equal parts, the long line will mark 10 seconds.

The number of subdivisions between the minutes of the vernier is usually the same as between the degrees on the limb, so that if the limb is divided into 15 minutes, then the divisions of the vernier are subdivided into 15 seconds; and if the limb is subdivided to 10 minutes, then usually the vernier is subdivided to 10 seconds.

Let the limb of an instrument, say a sextant, be divided to 10 seconds, that is to say that each degree is divided into six equal parts, and let the divisions of the vernier be divided into the same number, then each of the latter subdivisions denotes 10 seconds.

If the zero division on the vernier coincide with the line marked 20, then the reading is 20°; and if with the first or second long division, then the reading will be 21° or 22°.

If it coincides with one of the shorter divisions between the 20 and 21 degrees, the reading will be 20° and some 10′, 20′, 30′, &c.: then if it coincides with the second *short* line beyond the 20 minutes, the reading will be 20° and 20′; and if with the third, it will be 20° and 30′.

It very often happens, however, that the zero of the index does not coincide with any of the divisions of the limb, but that it lies somewhere between two of them. In this case we must observe how many degrees and minutes are denoted by the divisions and subdivisions of the limb which the index of the vernier has passed, and then look for a line somewhere on the vernier that does coincide with one on the limb. Now observe that the number of minutes and seconds from *that line to the zero of the index*, added to the number read off upon the limb, gives the angle required.

Thus, supposing the index to stand between 20 and 30 beyond 20 degrees, and the line on the vernier denoting 5 minutes and 10 seconds, to coincide with any one on the limb, then this last quantity, added to 20° 21′, gives 20 degrees 25 minutes and 10 seconds, which is the angle measured.

In the limbs of small theodolites the degrees are usually subdivided into two equal parts, denoting 30 minutes; and the divisions on the vernier are single minutes; a smaller subdivision must be estimated by the eye, which can be done to 30 seconds.

In our figures, above referred to, L B represents a portion of the graduated limb of an instrument, and V S a portion of the vernier scale, the zero point being at V.

In fig. 27 the limb is divided to 15 minutes, and these divisions are subdivided by the vernier to 15 seconds. The reading is 25° 46′ 30″, because the zero of the index has in the first place passed 25 degrees and the third division of a degree, which denotes 45 minutes; and the division of the vernier which coincides with a division on the limb, denotes a minute and a half, which, added to 25° 45′, gives the above angle.

In fig. 28 the reading is 20° 21′ 20″, because the zero of the vernier has passed 20 minutes beyond 20 degrees; and the division on the vernier which coincides with a division on the limb, indicates 1 minute and 20 seconds, which, added to 20° 20′, gives the above angle.

It will be seen that in every case the quantity indicated by the vernier is read backwards, from a division coinciding with one on the limb to the zero on the vernier.

In fig. 29 the reading is 21° 23′ 30″, because the zero of the index has passed 21 degrees and 20 minutes, and the division on the vernier which coincides with one on the limb, denotes 3 minutes and 30 seconds, which, added to 21° 20′, gives the angle above mentioned.

In fig. 30 the reading is 22° 2′ 10″, because the zero of the vernier has passed 22 degrees, and the division of the vernier coinciding with a division on the limb, indicates 2 minutes and 10 seconds, which, added to 22°, gives the above angle.

In reading off the limb of a theodolite or sextant, very much depends on practice, and also on the way in which the observer handles the magnifier, by means of which the vernier is read; the rim of one's hat, for instance, is often very much in the way, and it is often necessary to hold the hand so as to shade the readings from the glare of a bright sun on the white silver metal.

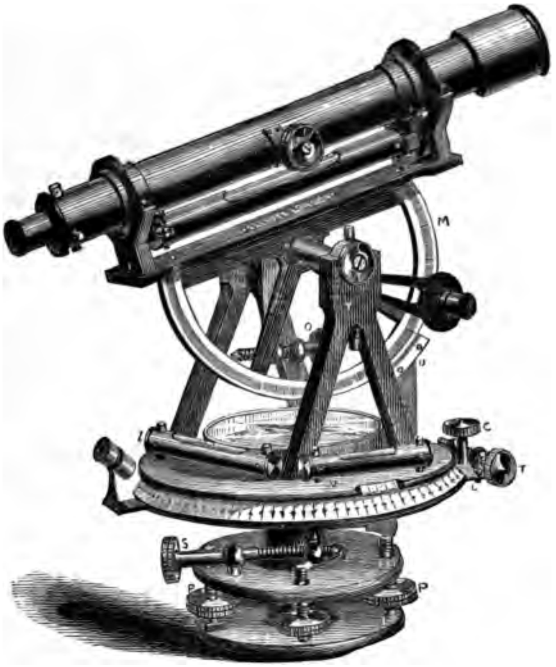
THEODOLITES.

The ordinary or Cradle Theodolite.—The theodolite is the engineering surveyor's chief instrument of observation for land or coast surveys, and for setting out work. It is principally used where the operations are on a large scale, as it is somewhat cumbersome to carry about, for which reason many of us prefer the box sextant, when we can possibly dispense with the theodolite.

These instruments are made of various sizes, the diameter of the limb indicating its size generally; thus we have 4, 5, 6, 7 and 8 inch theodolites; for geodetic operations they are very much larger; to the engineering surveyor we would recommend the 6-inch instrument; it is certainly heavy, but we may do anything with it, either in surveying or setting out.

The annexed figure represents a cradle theodolite, according to the make of Elliott Brothers, or Troughton and Simms. It consists in the first place of two circular plates, L and V; the first is called the limb, and the second, turning freely upon it, is the vernier plate.

Both have a horizontal motion by means of the axis shown underneath. This axis consists of two parts, external and internal; the former is secured to the graduated limb, L, and the latter to the vernier plate, V. Their form is conical, nicely ground and fitted to each other, and in well-made instruments they have a soft, steady motion. The external centre also fits into a ball, concealed in the figure by the parallel plates, and the parts are held together by a screw, partly visible in the cut, under the horizontal limb.



The diameter of the lower plate is greater than that of the upper one, and its edge is chamfered off and covered with silver, to receive the graduations.

On opposite parts of the edge of the upper plate, or 180° apart, a short space, V, is also chamfered, forming, with the edge of the lower plate, a continued inclined plane; these spaces also are silvered, and form the vernier, which we have described above.

The lower limb is usually graduated to thirty minutes of a degree; this however depends on the size of the instrument. It is subdivided by the vernier to single minutes. The six-inch may usually be read to twenty seconds.

The parallel plates, P, are held together by a ball and socket shown between them, and are set firm and parallel to each other by four milled headed screws, three of which are shown in the figure.

These turn in sockets fixed to the lower plate; they are set in pairs opposite each other; they act in contrary directions. The instrument by these means is set up level for observation. Beneath the parallel plates is a female screw adapted to the staff head, which is connected by brass joints to three mahogany legs. We should hardly have mentioned these, but for the fact, that it is with regard to these that the instrument often gets out of order. Many persons lean so heavily on them when setting up the instrument, that the screws get loosened and the instrument becomes shaky. These screws should be looked to occasionally, and, if necessary, they should be tightened. The legs are so constructed that, when shut up, they form one round staff, secured in that form, for carriage, by brass rings slipped over them.

When opened out they make a very firm stand, however uneven may be the ground. We may also observe, with regard to the material of which the legs are made, that we prefer deal painted black, this being of a larger size than that usually made, and considerably longer.

The lower horizontal limb, L, may be fixed in any position by tightening the clamping screw, which we have already referred to, which causes the collar to embrace the axis and prevent its moving. It is, however, requisite that it should be fixed in some precise position, more exactly than can be done by the hand alone; the *whole* instrument, when thus clamped, can be moved any small quantity by means of the slow motion screw, S, which is attached to the upper parallel plate, P.

In like manner, the upper or vernier plate, V, can be fixed to the lower in any position by a clamp, C. This also is furnished with a slow motion, the screw of which, T, is usually called the tangent screw.

The motion of this limb, and of the vertical arc, hereafter to be described, is sometimes effected by a rack and pinion, which is greatly inferior for so delicate an operation; this we only mention by the way, because many of these instruments are still to be met with.

Upon the plane of the vernier plate, v, two spirit levels, l l, are attached; they are placed at right angles to each other, with their proper adjusting screws. Their use is to determine when the horizontal limb is set level, as the bubbles should then be in the centre of their runs. A compass is also supplied in the centre of the instrument.

The frames, Y, support the pivots of the horizontal axis of the vertical arc, or semicircle M, on which the telescope is placed.

The arm which bears the microscope for reading the angles of elevation or depression which are denoted by the vernier u, on the vertical limb or arc, has a motion of several degrees between the bars of the frame, and can be moved before the face of the vernier for reading it off.

Another arm clamps the opposite end of the horizontal axis, by turning a screw, and has a slow motion tangent screw at o, by which the vertical arc and telescope are moved any very small quantities up or down, to perfect the contact, when an observation is made.

One side of the vertical arc is inlaid with silver, and divided into single minutes by means of its vernier. The other side shows the difference between the hypothenum and base of a right angled triangle; this gives the number of looks to be deducted from each chain's length, in measuring up or down any inclined plane, to reduce it to the horizontal measure. Such, at least, is the description and motive of the makers on this point, but we never knew of a surveyor having recourse to the process.

The long level which is shown under and parallel to the telescope, is attached to it at one end by a joint, and at the other by a capstan headed screw, which being raised or lowered will set the level parallel to the optical axis of the telescope, or line of collimation; there is a screw for adjusting it laterally to true parallelism in this respect.

The telescope has two rings or collars, shown over it, ground truly cylindrical, on which it rests in its supports, called Y's from their resemblance to that letter. It is confined in its place by clips, which may be opened by removing the pins which keep them closed, for the purpose of reversing the telescope, or allowing it a circular motion round its axis during the adjustment. This is a great recommendation in the cradle theodolite.

In the focus of the eye-glass are placed three lines, formed of spider's web, one horizontal and two crossing it diagonally, so as to include a small angle between them; a method which is better than having one perpendicular line, because an object at a distance, such as the foot of a ranging rod, can be made to bisect the said small angle, with more accuracy than it can be bisected by a vertical wire, which occupies space and obscures vision in the wrong place.

The screws adjusting this little piece of mechanism are shown near the eye end of the telescope; there are four of these placed in pairs, at right angles to each other; so that by easing one, and tightening the opposite one of each pair, the intersection of the cross wires may be placed in adjustment. The object glass of the telescope is thrust out by turning the milled head on the side of the telescope, that being the means of adjusting it to show an object distinctly.

A brass plummet and line are packed in the box with the theodolite, to suspend from a hook under the centre of the instrument. It is by this means that the vertical axis is placed exactly over the station from whence any observation is to be taken. This plummet we always cast aside; it is not one quarter heavy enough for the purpose for which it is intended, the slightest breath of wind setting it oscillating at the time it is wanted to plumb over the station; it is besides in a dangerous position in the box; we prefer a much larger plummet, which we carry in our pocket.

There are besides, if required, two extra eye-pieces, for the telescope to be used, for any astronomical observations. The one inverts the object, and has a greater magnifying power, and more light; it is this eye-piece which is now generally used, more particularly for surveying purposes. The other is a diagonal eye-piece, which is a great convenience for observing any object having considerable altitude; this, however, is sometimes left out of the box.

Line of Collimation.—This is the first adjustment to be looked at; the object of it is to make the intersection of the cross hairs of the diaphragm coincide with the axis of the cylindrical rings in which the telescope turns. This adjustment is known to be correct when, during an entire revolution of the telescope in its rings, the intersection of the wires, or cross hairs, continues fixed on the same point of some distant object.

The first thing to be done is to draw out the eye end of the telescope until a sharp and distinct vision is obtained of the cross hairs; this requires more care than may at first appear necessary; it is because of the extreme fineness of the spider's web threads. When these have been brought out sharp and clear, and the telescope brought to bear on the distant object, the object glass is thrust outwards by means of the milled head on the side of the telescope, until clear vision is obtained of the object in the distance; now move the eye right and left before the eye end, and see if in doing so the cross hairs are steady or whether they appear to move as the eye does; when this is the case it denotes parallax, and it is very common in fine bright weather; the eye-piece must then be very slightly moved, and also the milled head, until all appears steady, at the same time that distinct vision is obtained of the distant object and also of the cross hairs of the diaphragm.

We may now see about the actual line of collimation. First, make the centre of the horizontal wire coincide with some well-defined and motionless point in a distant object; then turn the telescope half round in its Y's, till the level lies above it, and observe if the same point be again cut by the centre of the wire: if not, move the wire one-half the quantity of deviation, by turning two of the screws at the eye end of the telescope, releasing one before tightening the other, and correct the other half by elevating or depressing the telescope; now, if the coincidence of the wire and object remain perfect in both positions of the telescope, the line of collimation in altitude or depression is correct, but if not, the operations must be repeated carefully, until the adjustment is satisfactory. A similar proceeding will also put the vertical line correct, or, rather the point of intersection, when there are two oblique lines instead of a vertical one.

The second adjustment is that which puts the level attached to the telescope parallel to the rectified line of collimation. The clips, being open, and the vertical arc clamped, bring the air-bubble of the level to the centre of its glass tube, by turning the tangent-screw, O, which being done, reverse the telescope in its Y's; that is, turn it end for end, which must be done carefully that it may not disturb the vertical arc, and if the bubble resume its former situation in the middle of the tube, all is right; but if it retires to one end, bring it back one-half, by the screw, which elevates or depresses that end of the level, and the other half by the tangent-screw, O; this process must be repeated until the adjustment is perfect; but to make it completely so, the level should be adjusted laterally, that it may remain in the middle of the tube when inclined a little on either side from its usual position immediately under the telescope; this is effected by giving the level such an inclination, and, if necessary, turning the two lateral screws. If making the latter adjustment should derange the former, the whole operation must be carefully repeated.

The third adjustment is that which makes the azimuthal axis, or axis of the horizontal limb, truly vertical.

Set the instrument as nearly level as can be done by the eye, fasten the centre of the lower horizontal limb by the staff-head clamp, leaving the upper limb at liberty, but move it till the telescope is over two of the parallel plate-screws, P; then bring the bubble of the level under the telescope to the middle of the tube, by the screw, now turn the upper limb half round, that is 180°, from its former position; then, if the bubble return to the middle, the limb is horizontal in that direction, but, if otherwise, half the difference must be corrected by the parallel plate-screws over which the telescope lies, and half by elevating or depressing the telescope, by turning the tangent-screw, O, of the vertical arc; having done which, it only remains to turn the upper limb forward or backward, 90°, that the telescope may lie over the other two parallel plate-screws, P, and by their motion set it horizontal.

Having now levelled the limb-plates by means of the telescope level, which is the most sensible upon the instrument, the other air-bubbles fixed upon the vernier plate may be brought to the middle of their runs by merely giving motion to the screws which fasten them in their places.

The vernier of the vertical arc may now be attended to; it is correct, if it points to zero, when all the foregoing adjustments are perfect; and any deviation in it is easily rectified by releasing the screws by which it is held, and tightening them again after having made the adjustment, or, what is perhaps better, note the quantity of deviation as an index error, and apply it, *plus* or *minus*, to each vertical angle observed. This, however, necessitates making a note of the error.

This deviation is best determined by repeating the observation of an altitude or depression, in the reversed positions, both of the telescope and the vernier plate: the two readings will have equal and opposite errors; one half of their difference being the index error. Such a method of observing angles is decidedly the best, since the mean of any equal number of observations taken with the telescope reversed in its Y's must be free from the effects of any error that may exist in the adjustment of the vernier, or zero of altitude.

The theodolite, as constructed in the manner we have described, is not inconveniently heavy, as the diameter of the horizontal limb seldom exceeds six inches; but when the diameter is increased, the other parts must be made proportionably large and strong, and the instrument becomes weighty and cumbersome to carry from station to station. The object of increasing the dimensions is, to enable the instrument to furnish more accurate results, by applying a telescope of greater power, and by a more minute subdivision of the graduated arcs. With the increase of size, a small variation takes place in the construction, and in the manner of attaching the supports to the horizontal limb, to afford the means of adjusting the horizontal axis, and making the vertical arc move in a vertical plane.

The transit theodolite is now the favourite instrument, though we do not consider that its adjustments are made under such favourable conditions as in the cradle theodolite, which we have just described; the great length of the standards, we also fear, is rather against it. Its great advantage, however, lies in the principle of construction implied by its name of transit; in setting out work, this is unquestionably a great recommendation, because, when the telescope requires to be turned end for end, it is merely necessary to make it revolve on its vertical axis, instead of having recourse to the troublesome operation of opening the clips in the cradle instrument, by the removal of pins every time this has to be done.

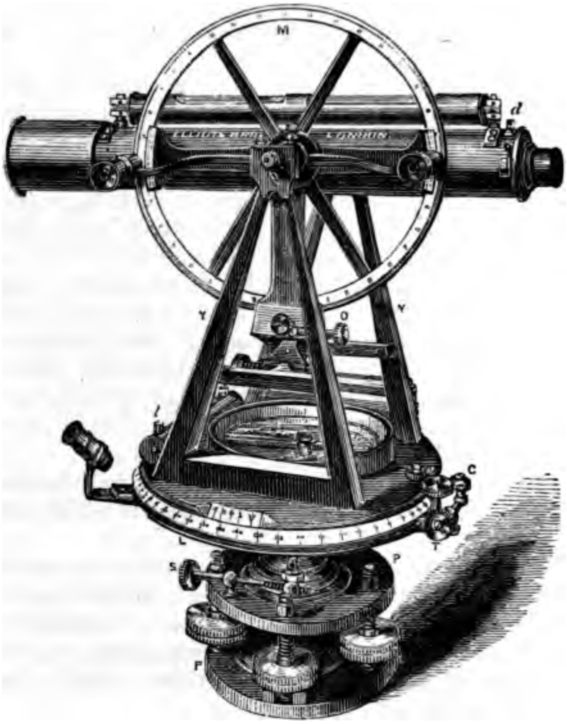
The illustration on p. 82 represents a transit theodolite of the usual construction.

The methods of adjustment are so similar to what we have already observed, that it would be needless repetition to give them again.

We may, however, make a few observations as to the line of collimation. Set up the instrument in the manner we have already described, and, by means of the parallel plates, bring the bubbles of the levels on the vernier plate to the proper centres of their tubes: do this carefully and as patiently as possible.

Select some well-defined object in the distance, and by means of the eyepiece and milled head of the telescope, adjust for distinct and steady vision; the way in which this is done has already been described. Mark exactly where the crosshairs of the diaphragm intersect on the object referred to.

Now, loosen the clamp of the horizontal limb, and turn the instrument bodily round. This will bring the telescope to bear at the eye end on the object of observation; therefore, reverse it by turning it end for end. Clamp the horizontal limb, and perfect the bisection of the object by means of the tangent screw S; now see that the bubbles of the levels are in the centres of their runs, which they should be, if the instrument has been turned properly out of hand. If there is any error in the collimation line, it may be corrected by means of the screws at *d*. Before doing this, however, release the vernier plate by loosening the clamp, C; turn the instrument half round, by the vernier plate, reverse the telescope as before, bring the crosshairs to bear on the object, and per-



fect the bisection by means of the tangent screw, T, after having clamped C. See to the bubbles, and examine if the distant object is well bisected, now that the instrument has been made to turn round *exactly* 180°; if not you may begin the necessary correction.

Now loosen the clips at the top of the standards, which hold down the axis of the telescope, and turn it half over laterally, so that the long level attached to the telescope will be downwards, and see if the collimation continues correct. All this, however, should be examined before the instrument is used in practice, and, if found incorrect, it should be sent back to the maker: this should be particularly looked to before going abroad; otherwise, the want of adjustment may be discovered at a very awkward moment.

The object of the above examinations is to see to the levels of the vernier plate as well as to the line of collimation. If the whole instrument is in adjustment, the centre of the diaphragm will intersect the distant point, after the telescope has been turned over laterally in its standards, just the same as it did before: if otherwise, the correction, by means of the screws *d*, will depend on whether the correction is required laterally by the side screws, or vertically by means of the top and bottom screws. Of course it is half the error which has to be corrected.

The telescope is in the next place brought back to its former or normal position; and again the correction is effected, if any is required. This is to be repeated until the intersection is correct, whilst the telescope is supported on the standards in both of the above positions. It is understood that, as regards the vertical intersection, the clamp of the vertical circle, or limb, M, is fast, and remains undisturbed the whole time. With regard to the verniers of the vertical arc coinciding with zero and 180°, when the bubble of the level of the telescope is in the centre of its run, we should only have to repeat what we have said on the same subject relative to the cradle theodolite.

THE EVEREST THEODOLITE.

This instrument, differing in many particulars from either of those above described, was first made by order of the late Colonel Sir George Everest, the talented superintendent of the Indian Trigonometrical Survey, by Troughton and Simms. A great number were sent out to India.

When an instrument with a large limb is required, this theodolite possesses many advantages. The figure on the following page illustrates one made by Elliott Brothers.

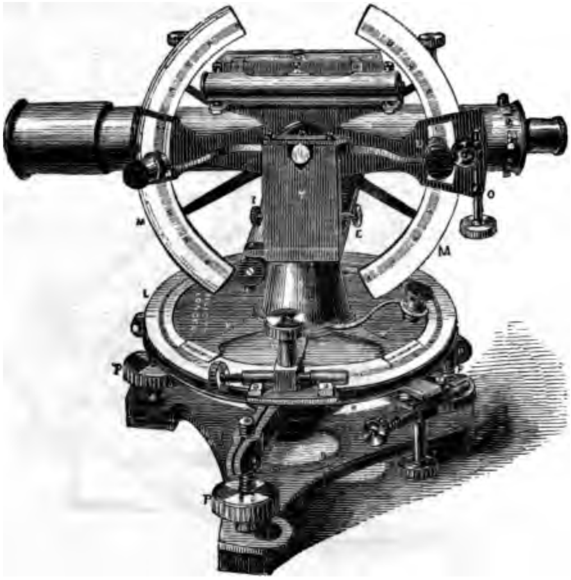
One recommendation is the broad base on which it stands, and the distance apart of the parallel plate screws, which afford the means of the most delicate horizontal adjustment.

The horizontal limb consists of one plate only, and the index is formed by three radiating bars, V, one of which carries a clamp for fastening the index to the limb, and a slow-motion screw. The instrument has the power of repeating, the horizontal limb being firmly fixed to a centre, moveable within a tripod support, and governed by a clamp and tangent screw.

The great advantage of the tripod stand is, that it can be very easily removed from the top of the staff, and placed upon a parapet, or wall, where the staff cannot be used.

The telescope is mounted in the manner of the transit, but the standard is of a much more solid description.

The vertical angles are read off on two arcs of circles, M M, which have the horizontal axis as their centre, and being attached to the telescope, move with it in a vertical plane.



An index, upon the same centre, carries two verniers, V V, and it has a spirit-level attached to it by which the index can be set in a horizontal position; so that whatever the position the telescope, and consequently the graduated arcs, may have, when an observation is made, the mean of the two readings will denote the angle of inclination.

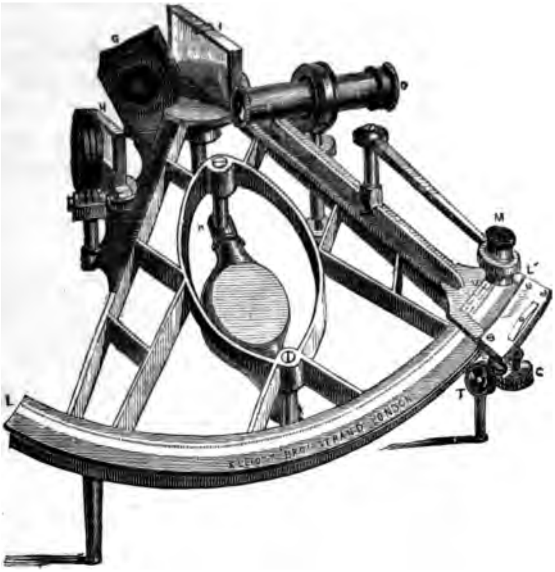
We may here observe that this will always be found the safest way of taking angles of depression, or elevation, with any theodolite whatever; it eliminates all errors of adjustment, and we invariably adopt it.

To set the instrument level, bring the bubble attached to the horizontal bar in a direction parallel to two of the foot-screws, and by their means send the bubble to the centre of its run; turn half round, and if the bubble has got out of its centre, correct half the deviation by means of the level itself, and the other half by means of the foot-screws.

This being perfected turn the telescope one quarter round, when the level will be over the third foot-screw, which must be moved to set the level correct. The line of collimation is adjusted by means of the collimating screws, and giving motion in Azimuth.

THE SEXTANT.

The sextant is not usually a surveyor's instrument; but for marine work—when the box sextant is used only with difficulty for very long lines, on account of its want of a useful telescope—the sextant proper offers many advantages.



The principle is exactly the same as that which has been given relative to the box sextant.

The instrument is represented in the above figure.

L L′ is the graduated limb, and I, the index glass fixed to the bar carrying the vernier V, and magnifying glass M. The horizon glass is shown at H: one half is silvered; the other half is seen through by direct vision, from the point O; the angle actually measured is that formed by the two glasses, that is the index and horizon glasses. Let it be noted that, in reading off on the arc of excess, either in the sextant or box sextant, the vernier must be read backwards. A clamp, C, fastens the index to the limb, and T is the tangent screw to perfect the coincidence of the two objects observed.

The ring which carries the telescope, O, is connected to the up and down piece, which enables it to be raised or lowered by means of a millhead; the object of this is to cause the objects seen directly and by reflection to appear of equal brightness, and to prevent parallax. The adjustment for distinct vision through the telescope is merely to slide the eyepiece backwards or forwards, as required.

There are several dark glasses, any of which may be used when the light is too intense for the eye, either as regards the index glass or the horizon glass.

The parallelism of the index and horizon glass is examined by the same means as those described for the box sextant; that is the disc of the sun. But for a more complete understanding of the mere construction of the sextant, we refer the reader to Mr. Heather's Treatise on Mathematical Instruments in Weale's series.

CHAPTER V.

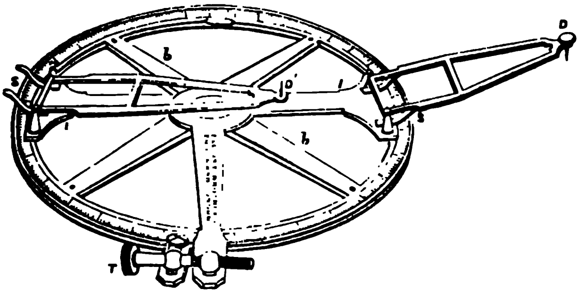
OFFICE INSTRUMENTS.

THE CIRCULAR PROTRACTOR—HOWLETT'S PROTRACTOR.

The instruments used in the office for laying down on paper the angles measured in the field, either with the compass, box sextant, or theodolite, are called protractors. The chief of these is

THE CIRCULAR PROTRACTOR,

shown in the accompanying figure, after the pattern of Elliott Brothers, and Troughton and Simms.



It consists of an entire circle, connected with its centre by the bars, *b b*. The centre of the metal is cut out, and a circular piece of glass fixed in its place; on this are marked two lines intersecting each other at right angles, and dividing the small circle into four quadrants; the intersection of the lines denotes the centre of the instrument.

When in use for laying down an angle, the protractor must be so placed on the paper that its centre coincides exactly with the angular point, from which it is supposed an angle has been taken on the ground; in fact, the point represents a station.

Round the centre, and concentric with the circle, is fitted a collar, carrying two arms, D D; in our figure, one of these is represented opened out, and the other closed in over the instrument; both of these arms, in the best instruments, have verniers at their extremities adapted to the divided circle. These are moveable by hand by means of an arm, connected with a clamp and slow-motion screw, T, by means of which any minute subdivision of the limb by the vernier is effected in the same manner as the tangent screw of the theodolite.

The branches, D D, of the arms carry, each of them, a fine pricker. These points and the centre of the instrument must be exactly in a straight line, or the instrument is not in adjustment. The points are prevented from scratching the paper as the arms move round, by means of steel springs, which lift the points off the face of the paper. After setting the centre of the protractor over the angular point, and fixing the verniers to their proper angle from the Field Book, a slight downward pressure must be given to the branches to cause the points to make a fine puncture on the paper; a straight line drawn through these and the station or centre of the protractor will give the line to form the angle required.

The glass centre-piece is placed as nearly even as possible with the under-surface of the instrument that no parallax may be occasioned by space between the lines on the glass-centre and the surface of the paper.

By means of the vernier, the protractor is graduated to single minutes, which, taking into consideration the numerous sources of inaccuracy in this kind of work, is the smallest angular quantity we can pretend to lay down *correctly*.

It will be barely necessary to observe that in the same manner as we can lay down one angle at a time with this instrument, so we may also lay down any other number.

The instrument is steadied on the paper by means of the short points which are attached to the under-surface.

HOWLETT'S PROTRACTOR.

Mr. Howlett, late chief draughtsman to the Ordnance, has made the following observations on the circular protractor above described:

'The circular protractor is generally considered the most perfect kind of instrument for plotting the angles of a survey; but against this instrument there are the following five objections:

'It is only steadied by being attached to the paper by pins; and in moving the arm it is liable to shift.

'As the vernier has to be set whilst the protractor is fixed on the paper and cannot be held to the light, it is next to impossible in some positions to see the divisions; or, if the protractor be taken from the paper, time is lost and error is caused by having to replace it on the working meridian.

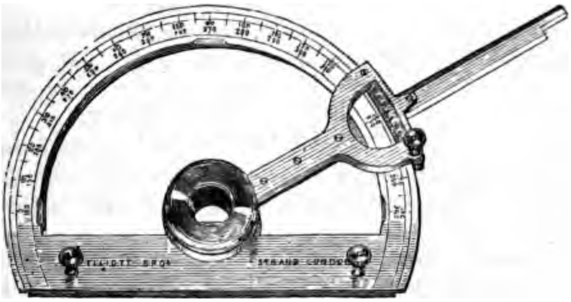
'When the whole set of angles required are set off and numbered they have to be transferred to the station, one after the other, with parallel rulers, in doing which much error creeps in, both while setting the edge of the ruler against the points, and then in shifting the ruler along to a distant part of the paper.

'It is a very delicate instrument, liable to be soon strained and rendered unfit for use.

'Lastly, the general inaccuracy which this method implies, for the sources of error are so many that the work cannot be brought to a close in a satisfactory manner, and when done it is little better than a survey plotted with a common protractor, where the degrees and half degrees only are marked.

'In making surveys of estates and parishes, while on half-pay, I suffered much for want of a better system of plotting than any I could find after making every inquiry and searching books on the subject. Such methods do not meet the exigencies of practical men, and hence it is usual to employ the chain alone. The theodolite is very little used amongst private surveyors; they reject the system altogether.* The theodolite is, however, an invaluable instrument,' &c. &c.

Mr. Howlett then describes his pattern semicircular protractor, of which we here give an illustration.



Of this instrument we can certainly speak most favourably, after having used it on important surveys, one of which was that of a large city abroad; at the same time, we cannot by any means subscribe to all the complaints he brings against the circular protractor, which we have found to produce very accurate results. The worst that can be said of it is, that it requires care; but, then, so does a theodolite: if either falls into bad hands it is soon injured.

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* It is to be remembered that Mr. Howlett refers to times gone by for some years. There are now few surveyors without a theodolite.

Mr. Howlett observes as follows when speaking of the above instrument:

'As, when away from home, it seldom happens that the surveyor can obtain a good drawing-board, or even a table, with a good straight edge, I fix a flat ruler to any table by means of a pair of clamps, and against this ruler I work the T-square, one side of which has the stock flush with the blade; or, if a straight-edged board be at hand, then the square may be turned over and used against that edge instead of the ruler. Here, then, is the most perfect kind of parallel ruler that art can produce, capable of carrying the protractor over the whole of a sheet of plotting-paper of any size, and may be used upon a table of any form. It is convenient to suppose the north on the left hand, and the upper edge of the blade to represent the meridian of the station.

'The protractor is held in the hand while the vernier is set, which is an immense comfort to the sight; and it will be seen that as both sides of the arm are parallel with zero and the centre, the angle may be drawn on the paper on either side, as the light or other circumstances may render desirable.'

From this description it is clear that angles taken with the theodolite can be transferred to the plot as accurately as the protractor can be set—namely, to a single minute, and that, too, in a rapid and pleasant manner.

'By means of the notch at the end of the arm, this instrument may be used in the manner of a circular protractor.' This is by drawing a pencil line along the edge instead of using the steel point in the circular protractor.

We shall have to return to the practical use of this instrument in a future chapter; in the meantime, we may here observe that, for all ordinary purposes, we consider this protractor most convenient and secure.

Besides the above two instruments, there is the cardboard protractor, to which we have already referred; and also a large size metal protractor, but without any vernier, which many prefer to any other description of protractor.

CHAPTER VI.

APPLICATION OF TRIGONOMETRY TO SURVEYING.

GEOMETRICAL MEMORANDA AND TRIGONOMETRICAL RULES—PRACTICAL TRIGONOMETRY; RULES.

THE complement of an arc is the difference between that arc and a quadrant or right angle; thus, 30° is the complement of 60°, the angle of 90° being made up of 60° and 30°.

The supplement of an arc is the difference between that arc and a semicircle or two quadrants of 180°; thus, 30° is the supplement of 150°.

Any side of a triangle may be taken as the base of such triangle; but for either the purpose of calculation, or that of plotting or describing on paper, it is always best to take the longest side.

The greater angles of any triangle are subtended by the greater sides, and its equal angles are subtended by equal sides.

The three interior angles of every triangle are equal to 180°, or two right angles.

Triangles with equal sides have also equal angles.

If two triangles have two angles equal, each to each, the remaining angles of each triangle will be equal to each other.

The exterior angle of any triangle is contained between a side and the adjacent side produced.

A B C is an exterior angle to the triangle A B D, and A B D is its adjacent angle (fig. 31).

The angles made by one line falling on another line are equal to 180°; so, therefore, are the adjacent and exterior angles of any triangle.

The three angles of any triangle being equal to two right angles, the exterior angle is equal to the two interior opposite angles.

Lines produced through the summits of equal angles described on the same side of any base line will be parallel to such base (figs. 32 and 33).

The segments of the sides of a triangle which are intersected by a parallel to the third side of the triangle are proportional (fig. 34):

DB : BE :: DA : EC, and AD : DB :: EC : EB.

The intercepted portions of such parallels will be to each other as the segments of either of the sides are to each other.

Lines produced through the equal and homologous sides of triangles also produced are parallel to the base on which such triangles are described (figs. 35 and 36). If the triangles AEF and CGH are equal to each other, and if AB is equal to CD, then BD is parallel to EH.

The sides of triangles containing equal angles are proportional. Any number of divisions of AB (fig. 37), through which parallels are drawn to intersect AC, will be proportionals to the divisions of AC; that is, A*b* will be to AC as AB is to AC, if *b c* is parallel to BC. If, then, we wish to divide any line, AC, into a certain number of equal parts proportional to the divisions of another line, as AB, we have only to draw AC through the point A, and, making an angle (the nearer to 60° the better) with AB, join BC, and through the divisions of AB draw parallels to BC to intersect AC; these parallels will divide AC into equal parts; as, for instance, for a scale, which will be proportional to the divisions of AB.

The two sides of a triangle containing any angle bisected or divided into equal parts by a line produced to intercept the third side opposite to the given angle, will be proportional to the adjacent segments into which the third side is divided. Let the angle A (fig. 38) be bisected by the line AGD.

Then, AB : BD :: AC : CD;
and BD : DC :: AB : AC;
and AE : EG :: AF : FG;
and EG : GF :: AE : AF.

Two triangles containing two angles, equal each to each, are similar triangles, and two rectangular triangles containing two right angles, and also any other angles, equal each to each, are similar triangles.

Any line drawn perpendicularly to and bisecting any chord of a circle, is a diameter to such circle (fig. 39).

Straight lines drawn through a circle, which are equal to one another, are equally distant from the centre.

The angle at the centre of a circle is equal to twice the angle at the circumference, both standing on the same base or chord (fig. 40).

Any angle in a semicircle standing on the diameter, that is, with one leg at one end and the other leg at the other end of such diameter, is equal to a right angle; and the angle contained by a greater segment of a circle than a semicircle is less than a right angle, and the angle contained by a segment less than a semicircle is greater than a right angle.

In any circle (fig. 41), a perpendicular from the circumference to the diameter is a mean proportional to the segments into which the diameter is divided by the perpendicular; that is,

AD : DC :: DC : DB.

To set out Perpendiculars on the Ground with a Chain only.—Let AB (fig. 42) be the line from the point O, on which a perpendicular is required. Make OC and OD equal to 50 feet, and drive in an arrow at C and D, so as to hold down a handle of the chain at each of these points. Take the 50 mark in hand and draw it out towards E; when the chain is exactly tight throughout, its centre will be at the point E, from which a line drawn to O will be a perpendicular to AB. To check the work, do the same thing at F; if true, EOF will be exactly in line.

To set out Parallels on the Ground.—Through the point C (fig. 43), to set out a line parallel to the line AB, set out any line DH and bisect it at F. From the point F on the given line, set out the straight line FEG; make EG equal to FE. Now take any other point on AB, but between F and B: measure CH, and bisect it as at I; set out FIK; measure FI and make IK equal to FI. If the work has been properly done G, C, K, will all three range in one line, and GK will be parallel to AB.

The measurement of inaccessible lines we have already referred to, and we shall here only give one or two more examples.

Let the line AB (fig. 44) cross a river of which the width is required; take a convenient point, and two others, C and E, on the base AB; the nearer the three sides of the triangle just formed are to equality, at a guess, the better.

Set out CDF, a perfectly straight line; measure CD, and make FD equal to it. Now make EDG a perfectly straight line; measure ED, and make DG equal to it.

Set up a rod at G, F and D, and range the lines GFH and BDH; drive a peg at the point of intersection H. Measure FH, which will give the length of CB; a check is obtained by measuring FG and EC, because they should be equal.

PRACTICAL TRIGONOMETRY.

The sine of an arc is a right line drawn from one extremity of the arc perpendicular to the diameter which intercepts the other extremity of the arc. AB is the sine of the angle O (fig. 45).

The cosine of an arc is the sine of the complement of that arc, or of the part of the diameter which lies between the centre of the circle and the sine. BO is the cosine of the angle AOB, and the sine of AOM. Therefore the cosine of an angle is equal to the sine of the complement.

The sine or cosine of any arc or angle can never exceed the radius; the secant and cosecant are never less than the radius; the tangent and cotangent admit of all possible degrees of magnitude.

The tangent of an arc is a right line drawn perpendicular to the diameter, at one extremity of the arc, and terminated by a right line drawn from the centre through the other extremity. TN is the tangent of the angle AOB.

The cotangent of an arc is the tangent of the complement of that arc. NT is the cotangent of the angle AOM, and the tangent MS of the angle AOM, is the cotangent of the angle AOB.

The secant of an arc is a right line drawn from the centre, through one extremity of the arc, and terminated by the tangent, or a line drawn perpendicular to the diameter at the other extremity. OT is the secant of the angle AOB.

The cosecant of an arc is the secant of the complement of that arc. OS is the cosecant of the angle AOB, and the secant of AOM.

The versine of an arc or angle is that part of the diameter which lies between the beginning of the arc and the sine. NB is the versine of the angle AOB.

The coversine of an arc is the versine of the complement of that arc. CM is the coversine of the angle AOB, and NB the coversine of the angle AOM.

The chord of an arc is a right line joining the two extremities of that arc, as AD.

The above belong equally to an angle as well as to the arc which is the measure of the angle.

If the sine or cosine, secant or cosecant, tangent or cotangent, be required of any angle greater than 90°, it is the same thing to find the sine, cosine, secant, &c. of the supplement, or what it wants of 180°.

The above sines are also called the *natural* sines, cosines, secants, &c., of the arcs or angles to which they belong.

The sine, cosine, secant, &c., of any arc or angle being of the same magnitude as the sine, cosine, secant, &c., of its supplement, as explained, it is evident that a table of these lines calculated for every degree, minute, &c. of the quadrant, or 90°, will answer our purposes for the whole circle.

In the tables of natural sines, cosines, tangents, &c., the radius is unity, and may be taken as 1 mile, 1 chain, 1 yard, &c., when the calculations deduced from calculating by the tables will also be miles, chains, yards, or fractions of them.

For instance, for the following angle, say 30° :—

The sine	will be	·50000,	equal to the	cosine	of 60°
The cosine	„	·86602	„	sine	„
The secant	„	1·15470	„	cosecant	„
The cosecant	„	2·00000	„	secant	„
The tangent	„	·57735	„	cotangent	„
The cotangent	„	1·73205	„	tangent	„

Having the sine of an angle to find the cosine, tangent, and secant.—Subtract the square of the sine from the square of the radius; the cosine will be equal to the square root of the remainder.

To find the tangent.—Multiply the radius by the sine, and divide by the cosine; the quotient is the tangent required.

To find the secant.—Square the radius and also the tangent; the square root of the sums will give the secant.

Calculation of plane triangles.—All the varieties of calculations that can occur in the solution of the sides or angles of plane triangles are comprised in the following three cases:

When two sides and their included angle are given.

When of three given things, two are a side and the opposite angle.

When the three sides of a triangle are given.

RULES.

When of the three given things two are a side and the opposite angle.—The sides of any plane triangle are to each other as the sides of their opposite angles; or, in other words—

As any side is to the sine of its opposite angle,
So is any other side to the sine of its opposite angle.

Or,

As the sine of any angle is to its opposite side,
So is the sine of any other angle to the opposite side.

Therefore to find the sine of an angle, begin the proportion with a side opposite to the given angle, and then having the sine, look in the table for the corresponding angle.

To find a side, begin the proportion with the sine of the angle opposite the given side, that is the side of which the length is given.

When two sides are given, and the side opposite to one of them, the question is sometimes ambiguous. Thus if the given angle be opposite to the least of the two given sides, the angle to be found by the rule may be either an acute angle or its supplement; but if it be opposite to the greater side, the required angle will be acute.

When two sides and their included angle are given.—As the sum of any two sides is to their difference,

So is the tangent of half the sum of their opposite angles, to the tangent of half their difference.

Then the half difference of these angles, added to their half sum, gives the greater angle, and subtracted from it, gives the less.

All the angles having been thus found the remainder may be obtained from the former rule.

When two angles are given, and the side opposite to one of them, to find the side opposite to the other.—This is a very common case, in harbour or river surveying, and in very many instances of surveying in wild and uncultivated countries, which in many places are almost or quite inaccessible.

As the sine of the angle opposite to the given side,
Is to the given side,
So is the sine of the other angle,
To the side required.

In fig. 46, let AB be the given side; ACB, a given angle opposite to it, and CAB the other angle.

Put C, for the angle ACB, and A for the angle CAB.

Then,

$$\text{sine of } \mathrm{C} : \mathrm{AB} :: \text{sine of } \mathrm{A} : \mathrm{BC}, \text{ required.}$$

Then,

$$\frac{\mathrm{AB} \times \text{sine } \mathrm{A}}{\text{sine } \mathrm{C}} = \mathrm{BC}.$$

Let AB measure 1000 feet; angle $\mathrm{A} = 63°$, and angle $\mathrm{C} = 57°$.

The natural sine of angle $\mathrm{A} = 63° = 0{\cdot}89101$.

The natural sine of angle $\mathrm{C} = 57° = 0{\cdot}83867$.

$$\frac{1000 \times 0{\cdot}89101}{0{\cdot}83867} = 1062{\cdot}4,$$

which will be the length of BC.

If now we take this length from a scale, in a pair of compasses, as a radius, and strike an arc with it from the point B, it will cut the line AC at C; a line drawn from C to B will be equal to 1062·4 feet.

If the base AB had been equal to 10·00 chains, then we should have had for the length of BC, 10·62½, or 10 chains, and 62·4 links.

Observe now that if the line AC is out at sea, as we here suppose to be the case, we get the point C, on the plan, where perhaps a sounding has been taken.

Farther on along the line, let C′ be another point where a sounding has been taken; required the length of C′B.

The angle A, and the length of the line AB remain unaltered; then, AB × sine of A, remains constant, and we shall have only to look in the tables for the natural sine of the angle C′. Let this measure 49° 30′, the natural sine of which is 0·76040.

Then,

$$\frac{1000 \times 0{\cdot}89101}{76040} = 11718 = BC'$$

Repeating the same operation as before, gives the point C′, and so we may go on to any length.

We might in the same manner have obtained the length of AC; that is by similar calculation; but we must first have subtracted A + C from 180°.

Then we should have had,

sine C : AB :: sine of BA : C.

In fig. 47 we have another example of the very useful application of right-angled trigonometry in the field.

The base line AB intersects several branches of a river. If we can ascertain the lengths of C_1, C_2, C_3, C_4, the details may be picked up at any future opportunity, and there is no risk of the correct measurement of the base being endangered.

Set out DA, equal to 500 feet, exactly at right angles to AB. This may be done with the theodolite or box sextant; if with the latter, set out D, at a considerable distance from AB. At the same time pole out 1, 2, 3, &c., on the base, which should be done also with the instrument, when we want accurate results.

Now measure the angles CD_1, CD_2, CD_3;

Let the first equal 35°
„ the second „ 50°
„ the third „ 75° 10′
„ the fourth „ 80° 5′.

It will be seen that CB is a tangent to these angles. We have therefore only to take the natural tangents * of these, multiply them by the radius DA, to obtain the consecutive lengths along CB.

Angles. Feet. Feet.
Tangent of 35° 0′ = 0·70021 × 500 = 350·1 = c_1
„ 50° 0′ = 1·19175 × 500 = 595·87 = c_2
„ 75°10′ = 3·77595 × 500 = 1987·97 = c_3
„ 80° 5′ = 5·71992 × 500 = 2859·96 = c_4

The calculations are very short, the work is easily done, and the results very accurate, if a little precaution is taken. For instance, each of the points 1, 2, 3, &c. should be set out from D, so as to avoid fractions of minutes, which are liable to introduce angular error, and complicate the calculations. Generally, even minutes, in such cases as the above, are unnecessary; because when at D, having ascertained the whereabouts of 1, 2, 3, &c., we may set the instrument to a full degree, and pole out accordingly, the assistant on the base taking care to keep himself on the line.

In the same manner as above we might have taken the angles at 1, 2, 3, and 4, but we should then have had to employ the tabular cotangents, instead of the tangents. The results would have been exactly the same.

Angles.
Thus, cotangent of 55° 0′ = 0·70021
„ 40° 0′ = 1·19175
„ 14° 50′ = 3·77595
„ 9° 55′ = 5·71992

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* For Tables of Natural Tangents, see 'The Engineer's, Mining Surveyor's, and Contractor's Field Book:' Second Edition (Lockwood and Co.)

CHAPTER VII.

THEODOLITE SURVEYING.

SETTING UP THE INSTRUMENT—SETTING OUT AND PRACTICAL EXAMPLE OF SURVEYING WITH THEODOLITE—PROTRACTING.

WE have given in the preceding pages a full explanation of the whole process of chain-surveying, and also of the construction and adjustments of instruments. We shall now, without any further reference whatever to these subjects, explain the use of the theodolite in the field, and in the first instance we will say a few words about setting out bases with the assistance of this instrument.

In fig. 48, let A and B be any two distant objects, which it has been determined to connect by a straight line or base; but there is some difficulty in setting out the line, because of high ground between the two stations, which prevents the one being visible from the other.

To set out a base line as A, B, the two points being invisible from each other, on account of high ground intervening between.—Take any convenient point as C, and with a sextant, or (better) with a theodolite, set out the angle of 90° ACD, and set up a pole at D, making CD, approximately, some 15 or 20 chains. Now measure the angle DCB, and subtract it from 90°. Set out the angle DCE, equal to the difference; CE will intersect AB at right angles. Let a pole be set up at E. Now set the sextant to 90°, and walk towards E, until with the sextant so set, you can see A and E, and B and E; this will be at the point F. If this point is on much higher ground than A and B you will not be able to do this exactly with the sextant, because the instrument is only capable to measure accurately angles made by objects in one plane; but you may come so near to it, that by setting up the theodolite once or twice, at first roughly, and then accurately, you will obtain precisely the point required. By these means, a long base may be set out with any degree of accuracy. For instance, having assumed the point C, and set out CD at right angles to AC, let the angle DCB measure 62° 30′. The right angle minus 62° 30′ equal to 27° 30′;

then make the angle DCE equal to 27° 30′, when CE will intersect AB at right angles; now proceed to find this point of intersection in the manner above explained. This method will be found more accurate than the following, which is only sufficiently approximate for short lines, or where accuracy is not absolutely required.

If from C we had set out a right angle, GCB, CE would have bisected the angle GCD.

The first thing, however, which we have to explain, is the method of *setting up the instrument.* We will suppose the tripod planted upon any convenient spot, the theodolite taken out of the box, and screwed on well home to the staff-head; that the plummet has been fastened on to the hook under the instrument by means of a slipknot, that it may be easily raised or lowered as required to suit the height of the instrument off the ground. When the instrument is fairly set up, this plummet should hang exactly over the station peg, which we suppose has been driven at C.

In doing this, we should as much as possible make use of the legs of the tripod, shifting one a little, and then the other, so as to bring the plummet over the right spot; in doing this, however, it is necessary to take care that the instrument is not thrown too much out of level, because it would have to be brought back by the parallel plates, and this would throw the plummet off the centre. It may be observed that in handling the legs of the tripod, they should be set firmly in the ground, but not too much so at first; gradually, as the plummet is brought over the station peg, they are fixed more and more firmly into the ground, so that you may walk round the instrument, and turn it round in the various directions required, without in the least affecting the legs of the tripod; if they were not firm, any external motion would disturb the instrument, and vitiate all the observations.

We now suppose all this has been attended to, and that we are about to set out the right angle ACD in fig. 48.

Clamp the vernier plate to the limb at zero, and perfect this by means of the slow-motion screw T; see that the other vernier is at 180°. Loosen the *lower* clamp, and turn the instrument bodily round towards A.

Before you will be able to obtain distinct vision, you will have to attend to the eyepiece, so as to make the cross hairs come out clear and sharp, and to thrust out the telescope by means of the millhead on the side of it. This has been more fully explained in describing the theodolite and its adjustment.

Distinct vision of the object at A being obtained, the bisection of the centre by the crosshairs is perfected by the slow-motion screw S; this in no way interferes with the connection between the vernier plate and the limb; but it moves the instrument a small quantity *bodily* round.

This bisection being perfected, see that the zero of one vernier is at zero, or 360°, on the limb, and that the other points exactly to 180°, as they should do, whilst the bubbles of the two levels on the vernier plate are exactly in the centre of their runs; the instrument is then in order to take any number of observations.

Of course it has been understood that when first setting up over the station peg, this was attended to by means of the parallel plates, P.

We have now to set out an angle of 90°; release the vernier plate, by loosening its clamp C. Turn the instrument one quarter round; do this gently, so that the body of the instrument may be in no way disturbed, as the zero of the limb should still point truly to the object at A. When you have brought the zero, or broad arrow, of the vernier nearly to coincide with 90°, on the limb, tighten the clamp screw, which you have just loosened, and then perfect this coincidence by means of the tangent screw, T. This *perfect* coincidence is examined by means of the magnifier attached to the limb. It should then be observed whether the broad arrow of the other vernier exactly coincides with 270°. This being so, the instrument is adjusted to set out an angle of 90°.

Send a man forward with a pole in the direction required, approximately, and lower the telescope; we suppose its clamp has been loosened, so that you may be able to see the lower part of the flag pole. You then make signals right and left, as required, until the pole has been set up; so that it is exactly bisected at the foot, by the centre of the crosshairs of the diaphragm. D is then at the angle of 90° required.

We may now see to measuring the angle DCB.

Without in any way disturbing the instrument, loosen the clamp C, and turn the vernier plate round towards the object at B; this you will best accomplish by means of the standards or Y's; when you have thus nearly brought the centre of the diaphragm on the object, tighten the clamp C, and looking through the telescope, perfect the bisection by means of tangent screw, T.

Look at your bubbles, to see they have not been disturbed; and then read off your angle by means of the vernier. Having noted this, you may loosen the clamp C, and turn the instrument round, over the 270°, towards the object at A;

when the centre of the diaphragm nearly bears on it, tighten the clamp, and perfect the bisection by means of the tangent screw, T. Now look to see if the broad arrow of the vernier exactly coincides with zero on the limb, as it did when you first started. This will test whether you have disturbed the instrument, *bodily*, in making your observations.

If all is well, you may now subtract the angle DCA from 90°, and add the difference to DCA, the sum of the two; you may now set the instrument so as to be able to set off the angle ACE, as required.

Or the instrument being last fixed on B, you may subtract the difference between DCA and 90°, from 90°, which will give you the means of setting off the angle BCG.

Without referring to this any further, because we have explained it at the beginning of the present chapter, we may suppose the point F, on the base, to have been found, and the theodolite set up in the same manner as we did at C.

We may now loosen the clamp C, and again bring the verniers to zero and 180°; tighten C, and perfect the adjustment by means of T. Loosen the clamp under the parallel plates, and turn the instrument round to B. When the centre of the diaphragm nearly intersects B, tighten the clamp, and perfect bisection by means of the slow-motion screw, S. This being made very perfect, loosen the clamp of the vertical limb, and turn the telescope right over, end for end, towards A; now look through, to see if A is bisected, which it will be if you have established your instrument on the straight line AB.

We will consider this to be the case, and now to range out the line AB—that is, to set up a number of poles, so that a straight line may be chained from A to B—you have only to proceed with the assistance of the instrument exactly in the same manner as we described at page 7, when setting out a base without any instrument.

If, on the other hand, we merely require the lengths from B to F, and from F to A, we have only to take the angles BCF and ACF, and proceed in the same manner as we did for fig. 47, making CF our base.

Practical Example of Surveying with the Theodolite.—We consider that our reader is now sufficiently acquainted with the use of the theodolite to be able to use it on a survey, and we shall, therefore, give a practical example of the way in which this is done, on the best and readiest system.

In fig. 49 we show the skeleton plan of an estate to be surveyed by chain and theodolite. As we have, however, fully explained the method of chaining and offsetting, we shall now refer only to the use of the instrument we are treating of.

Before commencing operations the surveyor will generally walk over and round the grounds he has to make a survey of. He will more or less definitively determine on his circuit lines, and also on the points in the interior, which he will make leading stations of. Looking at a piece of paper with a few lines upon it, all this appears clear enough; it is different when the irregularities of the ground come to be encountered. In our plan, for instance, everything is plain enough, because we can take in the whole at a glance. We should try to find a spot on our survey where we can do the same as much as possible; from such a place we can determine many of the points which can be made useful stations, and which can be observed from the circuit lines with which we purpose to surround the area to be surveyed. The larger this area the more important it will be to find a spot from which we can see as much of it as possible.

This we must now suppose to have been done, and also that we have determined on stations where the centre of the protractor is placed on our figure.

This spot has been selected because we there have two long lines down the road, right and left, and because it places the north point before us.

Set up the theodolite at this first station; level it, &c., as already described; loosen the compass needle, and send a man with a flag-pole up the road, as far as you can see, to station 2, and another to station 9, also as far as you can see, that is clear of obstructions.

By the time this is done, the compass needle will have settled steadily to the magnetic north. With the vernier plate firmly clamped to the limb, at zero and 180°, loosen the *lower* clamp, and turn the instrument bodily round, until the zero of the limb coincides with the magnetic north; this will disturb the needle a little, but it will soon settle again.

Having done this, loosen clamp C and at once turn the instrument round on station 2; perfect the bisection of the pole by means of the tangent screw T, and read off the angle 2, 1, N, that is the angle which the first line 2, 1, makes with the magnetic; note this angle. You may now again loosen clamp C, and turn the instrument round to line 1, 9; perfect the bisection, and read off the angle, which will be N, 1, 9, the bearing which the line 1, 9, makes with the magnetic.

Enter this also in your Field Book under the note last made: supposing there is a road going off in another direction from 1, turn the telescope round in this direction, selecting some convenient object at a little distance, and likewise read this bearing.

If there are any objects in the interior of our area of which we wish to fix the position in relation to our survey, and which can be seen from this station, treat them exactly in the same manner, and note the observations, one underneath the other, in the Field Book, in such manner that we shall be certain at any future time to be able to tell what they refer to.

Finally, bring the vernier plate back to bear on station 2, and see that it reads, after perfect bisection, exactly the same as it did before; this will be the case, if you have not in any way disturbed the theodolite, whilst taking the bearings or angles above referred to. We have now only to add, as regards this station, that we should as much as possible fix stations, 2 and 9 for instance, so as to make the readings at 5 or 10 minutes. This may be done by looking at the vernier as soon as we have bisected the pole, to see what difference there may be; then move the vernier back or forward, as most convenient, so as to make it coincide with some full division on the limb; then again look through the telescope, and have the pole moved until it is intersected, always at bottom, if possible, by the crosshairs. Let the pole be then held fast in this new situation, until a peg is driven into the spot.

Great care should be taken that this is always at a spot where the theodolite can be conveniently set up; generally this is best done by the roadside, and out of the way of observation as much as possible. We have paid no attention to this in our figure, which we merely want to make clear.

The observations being complete at station 1, the instrument is taken up and removed to station 2, where it is to be set up again, levelled, &c., as before. The first thing now to be done is to release the under-clamp; now turn the theodolite round, with the telescope reversed to bear on station 1; by means of the slow-motion screw S, perfect the bisection of the foot of the pole; observe that this makes no difference in any of the angles, as we do not interfere with the vernier; it only places the instrument in position. Look to the verniers, to see that there has been no disturbance.

The object of reversing the telescope is to place the circle of the horizontal limb in the same position relative to the magnetic which it held when the instrument was at station 1. If, for instance, the reading there was 28° north-west, then in the next station at 2, one of the verniers on the instrument will still be in this position—that is to say, the one that pointed to this angle, and the other vernier which lies exactly opposite to it, will point to station 1.

The bisection of the pole at station 1 being perfected, after the instrument has been set up at 2, turn over the telescope; loosen clamp C; turn the instrument round towards pole 3; tighten clamp C, and perfect the bisection by the tangent screw T. Read off the vernier; now observe that this gives on the limb of the theodolite precisely the same angle with the meridian as that shown as having been pricked off by the protractor at 3. That is, 3, 1, on the protractor is parallel to the line 3, 2, chained along the road, and they both make the same angle with the magnetic.

The observations having been completed at station 2, the instrument is taken up and removed to station 3, where it is set up over the hole made by the pole in the ground, and levelled. Now loosen the lower clamp again, and, with the telescope reversed, turn the instrument round bodily to bear on the pole left at station 2; tighten the clamp, and perfect the bisection by means of the slow-motion screw S; observe that we have not interfered with the vernier; we have only fixed the instrument in position as before.

The bisection being made perfect, loosen the clamp C, and with the telescope again reversed, turn the vernier plate round towards the pole at station 4; tighten the clamp, and make perfect the intersection by means of screw T; read off the angle.

Here again we may observe that this places the vernier, or the horizontal limb, exactly in the same position that line 4, 1, is on the protractor in the plan at fig. 49. The line 4, 3, along the road is parallel with 4, 1, on the protractor, and therefore makes the same angle with the magnetic.

From this point, several angles were taken with objects in the interior of the survey, these being shown by fine dotted lines; each of these angles of course makes an angle with the magnetic meridian, and would be shown in the same manner on the protractor. Observe, however, that after having made the first observation at station 1, on the needle, we have not again referred to it on the ground; we are therefore in nowise influenced by any local or diurnal variation of the compass needle. We merely take the vernier readings.

The instrument is now removed to station 4, set up, and levelled; the lower clamp is again loosened, and, with the telescope reversed, the instrument is turned round bodily to bear on station 3; tighten the clamp and perfect the bisection by means of the slow-motion screw S. Read off your verniers to see there has been no alteration from the last reading. Now loosen clamp O, and having again reversed the telescope, turn the vernier plate round to bear on the pole held at station 5; tighten clamp C; and perfect the bisection of the pole by means of the tangent screw T. Read off the angle.

The verniers of the instrument are at station 4, in the same position relative to the magnetic, as line 5, 1, in fig. 49, as shown by the vernier of the protractor. The line 5, 4, is parallel to the line 5, 1. It will be observed that at every remove of the instrument the first thing to do after levelling the instrument, is to loosen the *lower* clamp—that which is beneath the parallel plates—and to bring the instrument to bear on the *back* station, after having reversed the telescope; this perfected, we apply ourselves to the vernier clamp C, which loosens the vernier plate, enables us to turn it round, and obtain the required angles. In this manner, above described, we complete the circuit of our survey, repeating the same operations; we need not therefore refer to them any further at present.

Let it however be observed that on setting up the instrument at station 9, we have completed the visual circuit. Now the first thing we have again to do here, is to loosen the lower clamp, reverse the telescope, turn round to the pole at station 8, perfect the bisection, release the vernier plate by loosening the screw C; reverse the telescope, turn round to station 1, tighten the clamp C, and perfect the bisection. Read off the angle.

We have now the critical moment of the survey, because the vernier should now read precisely the same angle as it did when at station 1 we took the bearing of the line 1, 9. If this is exact, then the work is very correct, and if the chaining has been good the work will be perfect. It is seldom, however, this occurs so closely as we could wish, and there is often a deviation of four or five minutes; this will be the total amount of error, and should be divided over the whole of the observations or angles taken.

If, however, care has been taken, as we have before suggested, to adopt the plan of avoiding fractions of minutes, and even as much as possible to set up the station poles, so that the verniers shall read some five or ten minutes, it will be found that a very considerable source of error has been eliminated. As we have already explained how this is to be done, we need not refer to it again. We merely suggest the adoption of the plan, because on a very extensive town survey we made some years ago, and which was to be plotted to a very large scale for works, we were at first rather troubled as to how we should get rid of this general source of error. We were the more anxious about it, because an immense number of angles had to be taken, many of the bends in the irregular streets not being more than thirty and forty feet long; it was when considering over the probable causes of error that we thought of this one, and we had afterwards every reason to be satisfied with the results of the course we adopted. In the case of any grave error at station 9, you must work back upon stations 8, 7, 6, until the error has been found out.

With regard to stations in roads, we advise the surveyor as much as possible to get these by the roadside; in the first place, he will then not be disturbed by passing traffic, and if the pegs are well driven down, he will generally be able to find them again. As probably, however, he will be sure to require some of these stations again to chain side lines from, it will be necessary that he should be sure of it; besides the peg, therefore, we advise cutting two little marks in the banks in line with the peg; or cut a few notches on some of the sticks in the hedge: you may make a hole at the station and bury a piece of paper. Avoid, however, making holes in the central portion of the road, as this might be productive of fatal accident, and get the surveyor into serious trouble.

It often occurs that a large survey is often divided into several minor ones by the means we have above described; it is therefore very necessary that these stations should be made in such a manner that we shall be certain to find them again.

Protracting.—We may now proceed to protract the angles on paper, so that we may be able to get the exact form of our survey.

We shall do this by means of Howlett's Protractor, which we have described and explained the use of at page 87.

To use the protractor, we should have a sheet of perfectly flat paper, and a long pair of parallel rulers, or a T-square.

In the first place, draw in a line representing the magnetic meridian, up and down the paper, and through this draw another line at right angles to the first, representing the east and west points; see that you place these lines in a convenient part of your paper.

Exactly over the intersection of the lines place the centre of the protractor, so that zero and 180° shall coincide with the east and west points and 90°, or 270° with the north and south. When this has been very accurately obtained, press the protractor tight down on the paper, which will make it fast by means of the two little pins underneath.

We are now ready to protract. Take the Field Book and read off, in the first place, all the angles of the circuit; place these before you consecutively. Run the vernier of the index round to angle No. 1, making use of a pocket magnifier, if necessary, to lay off the vernier to the proper minute. It will be seen that the instrument is provided with rack and pinion, or tangent screw motion. Having got the correct angle, draw in a line along the edge of the protracting bar. The vernier may be now set to angle 2; that is, the angle taken at station 2, just in the same manner as the above.

In the next place, we may in the same manner protract the angles for 3, 4, 5, &c., to our last observation, and we may take up our protractor, after having ascertained that the work has been correctly done. Care should be taken to run a little circle over every line protracted, with 2, 3, 4, 5, &c., marked in it, to refer to the particular angle which each line refers to.

We may now take a straight edge, and draw in the line 1, 2, the first on the survey; we then take the scale to which we intend to plot the survey, and set the zero at the point of intersection 1, and the edge along the line. We then prick off the length of the first line to station No. 2.

We now take a pair of parallels and lay the edge at 1, 3, and run the rule up to the end of line No. 1, as last plotted; draw in a straight line along the edge of the ruler, through station 2; this will fix the direction of line 2, 3. Set the zero of the scale at station 2, with the edge along the line last drawn, and prick off the length of the line 2, 3. We proceed in the same manner until we get to the end, which will complete our circuit.

We have already made some remarks about the parallels and plotting in this manner when describing the protractors.

The other way of proceeding is by means of the T-square.

Let there be any straight-edged rule fixed, as at AB (fig. 49), or, if this is not necessary, let there be merely a straight line drawn there: either of these must be parallel to the line representing the magnetic north, and the line representing east and west should be drawn in with the T-square.

Let us suppose that line 1, 2, has been plotted; we have now to run up the T-square towards station 2, in such manner that we may lay the lower part of the protractor against the edge of the T-square, whilst the centre of the instrument lies directly over the station 2. The vernier of the protractor having been set to the angle 2, 3, it is laid off; the line 2, 3, is then run in with the straight edge, and plotted off with scale.

We have now to protract the angle 3, 4. For this purpose we handle the T-square just as we have above, and as it is shown in the figure, bringing the blade towards station 3, whilst the centre of the protractor, set to the proper angle, is laid over the station. In this manner we lay off the line 3, 4, and then plot in its length with the scale: it is needless to explain this any further, because the figure 49 almost explains itself entirely.

When the survey is very extensive, or when even an ordinary survey is plotted to a very large scale, we cannot trust to parallels, nor can we expect to find T-squares long enough for our purpose. In such cases we must plot as far as we can by either of the means just pointed out, and through the last station pricked off, we must lay down a new magnetic and east and west lines; at this point we may again use the protractor for laying off another set of angles. To produce correct work, considerable care is necessary to make this second magnetic parallel to the first; for if it is not exactly so, the pains taken with the theodolite in the field is so much labour lost. The best method, and the most simple, is that we shall describe in Traverse Surveying, in a future chapter.

CHAPTER VIII.

ENGINEERING SURVEYS WITH INSTRUMENTS.

ROAD AND RAILWAY SURVEYING WITH INSTRUMENTS; SETTING OUT; THEODOLITE; BOX SEXTANT—EXPLORATION SURVEYS; CANALS AND IRRIGATIONS; HILLS AND WATERCOURSES—LEVELLING BY INCLINATION—TRACING LEVELS IN HILLY COUNTRIES.

We will now go rapidly through the description of a railway or road survey with instruments, because we have already referred to the subject of railway surveying with chain only. The exploration portion of the subject is considered farther on in this chapter.

The first thing to look out for on getting on to the ground, with map in hand, is the highest spot from which we can see in both directions, back and forwards if possible, and as near the line of works shown as may be convenient.

The first spot we happened to select was A, fig. 50; not because it was exactly on the line, but because we had very high ground close by, from which we could see in both the above-mentioned directions.

From here we determined to set out the line A B. For this we selected a tree in the distance, taking care to clear the corner of the wood on the left hand. The chain was cast out at once at A, and a man set it forward with poles and whites, and instructions: see page 7.

Standing at our starting-point, and looking right on towards A, we commenced sketching-in some of the fences, whilst the chainman was laying out the first chain. Before we had laid out more than eight or ten chains, the man we had sent forward was waiting for instructions, at the fence beyond the first brook; we knew that before we could reach the hollow we should lose sight of our forward object.

When, according to our directions, he had set up the mark we wanted, he started for the brow between the two streams; we considered that this brow, as we ascended from the hollow, would also hide our forward object. From here we started on for the corner of the fence beyond the second stream, because we knew that we should here have a repetition of what occurred at the first brook, &c., &c.

Now we want two things to be particularly considered by the student. Before we started this man forward with the poles, we thought first as to what we should require him to do; this was, that we should always have a forward object to sight upon, and that the chainmen should never be kept waiting. We explained this to our pole-man, and, from the high ground at A, showed him pretty nearly where we should require marks to be set up, making him also understand that he must look out to see where, on the line, the forward object B would be lost sight of.

It must also be observed that whilst we had point B to guide us, he might be guided in the same manner by a tall pole left at A; by these precautions, and the line given by men who were chaining, we had always the means of keeping the line true, so long as we took care to do it beforehand, and before losing sight of everything, backwards and forwards; where a fence only was in the way, we selected anything in it to guide us until we crossed.

All this is extremely simple, but on its being carried out intelligently depends almost entirely the slow or rapid progress you may make in the course of the day. Everything should be so arranged that the chainmen should never have to stop for want of the means of going on with the line. By adopting the method we have above described, it will be found that all these matters will be kept right.

As the chain-work is proceeding we of course have stations for side lines. For instance, we shall want to chain to *g*, *k*, *l*, to pick up fences and brooks, &c. We always fix the directions of these by the box sextant; that is to say, we take the angles which the chain lines will make with the base.

In many cases where there is not a great deal of work on them, we sketch in the Field Book the angles which the side lines make with the base, noting the correct angle of course by the side of the line, and run it out at once in the same page of the book that the base line is fielded in. Where the work is intricate, we use another page, as explained elsewhere under the heads of 'Chaining,' and 'Field Book.'

We may now suppose we have reached the point B; of course it is considered that we recollect enough of the country to remember the fence C C.

It is not important, as regards fences, whether the chain line is half or even a whole chain one way or the other; we took a tree in the distance, on high land, out of our plan: we had poles set up down in the hollow road, and upon the next brow, and from B started for C. Before moving on, however, we took care to drive a peg at B, for theodolite purposes; we did the same at C, when we set out the line DCE. This we chained, and afterwards EF; and then the long line FG, which was produced some distance beyond G.

But up to the present time all these lines are lying loose; they could not be plotted. When we considered we had done enough to give us a morning's work with the theodolite, we took the instrument out.

The instrument was set up first at B, where we took the angles ABF and ABC. It was then taken to C to fix ED; and to E, to take the angle DEF; and lastly, to F, to take the angle EFB. This determined the position of FG. The remainder of the work was picked up by running lines between the bases. The theodolite was then taken on to A, to set out H on AB produced, and afterwards to take the angle IHB.

EXPLORATION SURVEYS.

Previous to beginning an actual survey, in the sense in which this word is generally accepted, the country to be traversed should be visited, to the extent of being able to ascertain the number of routes that can be taken; the value of these routes will depend on the minimum of cost for lands and works, and the maximum of traffic that may be obtained; so that the cheapest line may not after all be the best, unless we can see means of diverting the traffic on to it.

Necessarily this involves an examination into the trade and importance of even small towns and villages: not only as regards their actual state, but the alterations to be produced by railways, roads, canals, tramways, &c.; therefore, not only the actual state, but the capabilities of such places require to be looked into.

Geological features are often of the greatest importance; mines of coal, iron, copper, lead, &c.; quarries of limestone, slate, marble; or the situation where these may be found should be carefully examined; all existing or possible manufactories; the state of agriculture, and the alterations that may be brought about by the proposed works.

All possible information should be obtained as to the existing cost of transport, the routes taken, and the means of locomotion.

Great care should be observed in gaining all the knowledge that may be acquired as to the different levels of brooks, streams, and rivers, more particularly the flood levels, ordinary and extraordinary; because these will determine location of works, the heights to which they must be carried, and the position and capacity of reservoirs.

With regard to rivers, it is very important to ascertain where, in times of unusual floods, branches of the river may break out; if any of the sites of these are known amongst the inhabitants, they should be carefully traced.

The question of materials for the works is an all-important one, and should obtain the surveyor's best consideration; the existence of gravel, sand, clay, stone, and timber should all be very carefully inquired into; as also the labour to be obtained from far and near.

In obtaining information upon all these points, he should, of course, investigate, as much as opportunities offer, for himself; at the same time we strongly urge him to avail himself of all local information. He will find opinions generally to vary to an important extent—often from interested motives, and often also because of the different views which men take of the same subject.

All these conflicting opinions should be noted, and carefully investigated as opportunities offer.

The most economical works are generally those which are made entirely at a high level or a low one, a summit or valley line; we cannot, however, always obtain these entirely, and are often obliged to reconcile the two. This point is one that gives the greatest trouble in a reconnoitring survey.

All summits to be crossed, the most favourable points where this may be effected, the materials to be cut through, the sites and nature of the inclines that may be adopted to reach them, the brooks or streams that may or must be crossed, or that may be contoured, are amongst the surveying points that must be examined; not minutely or fastidiously, but with sufficient observations to give a fair idea of different routes, and consequently sections, that may be adopted.

It is no longer a question of cottages, and the exact number of outbuildings; of fences and their bends; of footpaths and a few inches of difference in the level of the roads; or 'standing orders,' in short. It is a broad and sensible examination of a country that is required, with just so much topographical information, and notes of observations, as may guide an engineer in determining upon one line in preference to half-a-dozen others.

Hills to be passed, valleys to be crossed or contoured, bridges or possible aqueducts over streams or brooks; the greater or less plentiful supply of water, particularly at summit levels for canals and irrigation works; the state of springs, and often underground drains, which we have known to carry at times enormous quantities of water, unperceived, and therefore uncertainly accounted for; their existing appropriation, and how they may possibly be made use of.

The general angle of inclination of hills and valleys, with the bearings of such lines, will often be found of the greatest value. If there be no general map, it is such a map that he will have first to construct; a few bearings laid down so as to be able to pick up the general position and contours, or rivers and streams, roads, woods, villages, valleys, and summits, will often give him the very thing desired; the great requirement in many such cases is about the same information as may be acquired from one of our best sheets of Ordnance Map, and to look after details in such matters is often not only waste of time, but occasions the neglect of other matters, in other places, which are far more important.

In the matter of surveys for irrigations and canals, we often meet with large quantities of gravel or sand, which would be more desirable on railway works; it is often of the greatest importance to ascertain whether these are water-bearing; a cutting made through them, unless very expensively puddled, will often drain away all the water for miles; this may often be a desirable event; but sometimes, however, it is the reverse, and with important consequences.

For such works as the latter, canal, &c., attention should be given to the points where, by contouring, long levels may be obtained without incurring excessive expense. The engineer will have to examine the ranges of high lands that are to be crossed, and whether adjacent ones can be connected, by long summit levels, which will diminish the difficulties in supplying the canal with water, as every junction of summits saves the water of two lockages.

It supplies, besides, so many more points where the canal may be supplied with water from springs and rivulets above its level.

A benefit arising from these long canal levels is often the bringing together of several locks, which enables them to be more effectually looked after, better worked, and more economically kept in repair; this often obviates great waste of water, and saves the expense of erecting lock-houses.

When the declivity of the country runs transversely to the course of the canal or watercourse—which will generally be the case along the sides of hills, at an elevation above the irregular ground at their feet—in those situations, the great falls, or inclined planes, may be made at the fork of rivers, so that the upper levels may branch up the valleys, and increase the communication or distribution of water.

The advantages of being able to conduct a canal, or aqueduct, upon watertight strata, instead of rocky and porous soils, without losing sight of other important considerations, is necessarily self-evident; the examination therefore of the strata, more particularly where we expect to be in cutting, is of greater importance than even in railways.

The summit level being traced, it will be time to look for the place where there should be a fall for two or more locks; the level of this fall being marked, it is to be traced, until an opportunity occurs, for a couple more locks, or one, if it is unavoidable.

The places of the different sets of locks, and the line between them being adjusted, the level is traced on, until an obstacle presents itself; this may be a total change in the course of the valley the line was pursuing, so as to render it necessary to begin to mount another valley towards a new summit.

It may happen, in tracing such an outline, in case of a change of the direction of the valley rendering it necessary to leave it, that some other valley may be at no great distance, into which the canal must be conveyed by a tunnel or deep cutting.

Now, in order to render this more practicable, it may be necessary to retrace our steps, and deviate the back line to a new and much higher level, by leaving out one or more of the locks and so avoid a tunnel, or at any rate very much shorten it. Supposing we have now got into the new valley, the same course is to be repeated until another change in the main direction is necessitated, when we may have to ascend a new valley or plane to a new summit.

To the new summit it will be requisite to proceed, and after settling the height of the summit level, and taking all the necessary steps for ascertaining the supply of water, and other circumstances of this summit, the levels may be traced from this summit downwards, working backwards or up again, as often as obstacles may render it necessary, until the former work in the valley is met, and a proper junction of them contrived.

For explore surveys, these levels are of course conducted with the utmost possible rapidity; enough has been said to explain this fully, for it will be seen that in our first examinations, without any levels, we may have to go over nearly the same ground several times.

Watercourses, and all traces of them, pursued to their summits, where they originate, or point out the first depressions of the valley to which the stream is making its way, are generally our best guides in finding the lowest passes in mountainous and hilly districts.

Hills very frequently run in chains, or ‘backbones,’ as they are often termed. We also meet them in groups, or isolated, when they certainly give us less trouble, because we can generally run away from them more or less, and get round; we say generally, because where the groups are frequent and close, and we have to make our way amongst them, it often leads to heavy works in getting from one to the other, unless the levels are closely studied, and the highest parts of valleys, accessible by curves, are carefully sought after.

In hills and mountains, which occur in chains, we have often to face them, and seek out their weak points. It is in volcanic countries this usually gives us the most trouble, because the high ground starts suddenly and abruptly out of the plains.

It is in such circumstances, and particularly in countries covered with thick wood and jungle, that we find the value of tracing watercourses, on either side of the range; they will give us those points where the lowest levels occur, along the flanks of the chain, and between the projecting spurs.

In seeking the lowest level, the descending water has adopted the line of greatest slope. In tracing this lowest level, upwards, we may find that, as an actual stream, it has disappeared, particularly in hot weather—we may even get beyond the range of the dried-up water-channel; but we may come to some swampy or soft places here and there, where we may notice a change in the vegetation, and we may often follow up, even to the original source in some wooded flank, by traces of moisture, which may be more particularly evidenced by the more rank vegetation of the undergrowth.

We may also observe that, supposing for instance we have determined on crossing a stream at a given point, and that we are aware a parallel stream occurs farther along the chain of hills, we know that we shall, more or less, have to contour back on the spur, in order to get across the ridge intervening between the streams.

We also know that if we are endeavouring to cross the summit of the chain at some point, either by a tunnel or cutting, we must cross the next stream at a higher level than the first, so that any trial levels traced up such streams are valuable guides.

It is generally at a bend in the stream, or a little above the junction of branches, if these occur, that we shall find the best pass.

When in a hilly country, or in an irregular and broken valley, it is usually by pursuing the track of the most important brook, or that branch of it which has the longest course, that we shall find out the lowest pass.

If along the opposite flanks of a chain of hills we can trace, towards the summits, signs of watercourses, we shall find passes; and, generally, if we can trace several of these, we shall find that the most important will point out the lowest of these passes, because it is fed by a greater area of watershed, or because of some very sudden depression.

Such indications as the above, and the tracks taken by the native traffic, carried by camels or mules, are generally the safest guides for our first explorations.

It is to such points as these that the first levelling operations should be conducted; nor is it absolutely necessary, in taking such trial levels, that we should ascertain everything by means of the levelling-staff. We may often take a sight to some distance across a small valley, selecting some distinct object on the other side, such as a large tree, or lump of rock. The depth of an intervening space may frequently be arrived at, by seeing where the line of sight intersects any tall tree, if there be any, and, on our road afterwards, measuring its height by means of a tape.

To be particular about a few feet, in matters of exploring the levels of a district, very often leads to a wretched waste of time; the engineering surveyor may often have to go over a great extent of country, in a very short space of time, and without any other assistance than that of a gang of native labourers. If he selects a line at haphazard, and regularly levels over it in the orthodox manner, he may afterwards have to regret that he has found a very bad line. If, on the contrary, the weak points of a chain of hills are first of all found out, and approximate levels obtained, he will be in a very much better position to trace a favourable line of section.

It is only when we happen to find a long, flat, and unbroken slope, along a chain of hills, that we can safely venture to creep up obliquely at once. Where the general line of slope is broken by numerous spurs, projecting more or less into the plains, it requires some preliminary rough study of comparatively highest and lowest points.

In such districts the high grounds rise and fall suddenly from some 50 to 150 feet, and it is of importance to know the intermediate levels and gain some information about the natural slopes of the hills and the intervening valleys.

Even when a line has been roughly selected by means of natural traces of levels, such as watercourses, or existing lines of traffic, it is almost always necessary to obtain some levels, four or five hundred yards or more on each side.

Running trial lines with the level, under such circumstances, or taking numerous cross-sections with the same instrument, is simply endless work, if anything effectual is to be done.

If, on the other hand, we adopt the means of getting at levels by means of angles of inclinations, and making use of tables for reducing to verticals and horizontals,* we may get over an enormous space of country; very often without moving from one line, but by observing right and left, with a staffholder on either side, to whom instructions have been previously given, as to the spots they are to go to, we take a number of angles of elevation and depression; we have only to book these, and get the distances chained, to obtain all we require in the field; and we may here observe that a micrometer in the telescope of the theodolite will save the trouble of chaining.

We are fully aware that this may not give perfect accuracy in measuring, though we know that on many occasions it is better than rough chaining. But even supposing the chaining is wrong to the extent of two feet in every 100-feet chain, the error will not extend to two feet difference of level in a length of five hundred feet.

The following account of some operations in Indian Engineering will point out that we are by no means singular in advocating this plan of proceeding for rough levels of approximations:—

The labour of tracing a mountain road through thick jungle, and over really rough broken ground, is greater than that expended in the actual laying out of the sheer descent of the ghaut itself; but it requires not a little scientific experience to pitch upon a general line for the latter, that will give scope for running a trace at a fixed gradient of 1 in 20, without having recourse to the clumsy expedient of zigzags. Either a deep ravine or valley should be sought, up whose flank the road may be carried; or a long spur or series of spurs, round and about which it may wind, should be chosen: and where such formation can be found, a combination of both features is best. Much deliberation and care have to be exercised at the outset, in judging by the eye of the practicability of the site chosen for the descent.

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* For a set of tables for this purpose, see the 'Engineer's Field Book,' second edition, 1867. (Lockwood and Co.)

The jungle is so close in North Canara, that a trial trace cannot well be run without great loss of time and useless expenditure of labour; all which is saved by having the ground reconnoitred by an experienced engineer, who, with the help of the aneroid barometer, can pretty accurately settle the question.

The head of the ghaut is usually a fixed point; and if it is not left open to doubt that it must be adopted in any case, the tracer may commence his line, working downwards, wherever his levelling-staff carries him, recollecting he must ease off his slope a little when turning corners, and must cross all streams at a dead level.

Once he has started, it is impossible to lay down fixed rules for his guidance, and there is frequently an ample field for the display of ingenuity and talent before he reaches the level ground beneath; in truth, to pilot his instrument through the Canara forest calls for the involuntary application of not a few principles of inductive philosophy.

For such work, in such a country, it may be imagined the common spirit-level is eminently unsuited. Weighty to carry, and cumbrous to set up in position, where the operator can barely find room to stand, and where a clear prospect of even a dozen yards in front of him is not to be obtained without felling the scrub which hinders advance and obstructs the views, its use has been wisely discarded in Malabar and Canara.

The instrument employed is what is known as the Gunner's quadrant or level for setting mortars at their proper angle, modified a little. The long bar is fitted with sights at either end, and has a universal joint screwed on at its centre.

The quadrant is reversed from the position it occupies in the mortar quadrant, having the arc turned inwards and the radius outwards towards the tracer. An armature, bearing a small spirit-level at its side and a vernier to read minutes at one end, works on the arc, which, to enable the level to be used for tracing either up or down hill without reversion, has an excess arc of some 50° on the upper side of its zero point. Seeing that an angle of 3° corresponds to slope of 1 in 20, an arc of 90° is considerably in excess of the angular accommodation necessary in tracing roads; and Messrs. Elliott Brothers might with advantage curtail this overbalancing appendage; they might also put the spirit-level in permanent adjustment.

The tracing quadrant is fixed to a light stick, shod with iron, of a length sufficient to bring the pin-hole of the sight within easy distance of the eye. The stick should not terminate in a point, or the levels will be vitiated. Its base ought to be about one inch and a half in diameter.

The forward staff is rather longer than the foregoing, but has a fixed vane, painted white, whose centre is exactly the same height from the ground as the pin-hole of the quadrant sight. The centre is denoted by a dot in the middle of a black horizontal line.

Furnished with this simple instrumental equipment, and accompanied by an intelligent man to hold the staff, a goodly lot of pegs, and half a dozen active men with billhooks, the tracer begins his toils.

Having set his arc, the staffholder is sent on 50 feet or so, along a path rapidly cleared by the woodsmen aforesaid, and moved by hand-waving till the crosshairs and vane-spot coincide, he using one eye to catch the vane and the other to observe the bubble simultaneously. Thus peg after peg is driven, and the trace proceeds with a rapidity proportional to the clearness of the ground and the necessity for preliminary examination.

It is a great advantage to have the pegs as close to one another as possible; for the more there are, the less risk is there of the true slope being lost when the excavation commences; a beginner is apt to put in too few rather than too many.

A party of fifty labourers follow on the heels of the tracer to open out a bridle-path a yard wide.

The pegs thus laid down are on the centre line of the future road, and when opening the gauge path the labourers are careful to stretch a strong line from peg to peg, by means of which the gradient is rigidly worked to. Before excavating, an upper row of temporary pegs, three feet higher up the hillside than the centre pegs, is inserted to denote the edge of the cutting in a like manner with the aid of string. If all these precautions are attended to, an even path upwards of a yard wide is speedily formed, and the slopes are preserved for ever.

If nothing further is done to it, this path itself is often an immense accommodation to both men and animals; while it enables the engineer to see his way much more clearly than if he had to grope through the jungle without so safe a guide.

Any improvement in direction which suggests itself is staked out after a thorough examination of the trace, and it is not seldom that the adoption of a deviation here and there is advisable. A road, it has been mentioned before, through the hilly district of Canara, is more troublesome to trace than the incline of a ghaut. This is due to the difficulty of determining by the eye alone how particular features had best be dealt with, and it requires a great deal of care and practice to escape committing mistakes in choice of gradients, and thereby losing both time and temper from being obliged to do work twice over. As a general rule, the saddles over which the road must go are first inspected; and it often happens that a small depth of cutting at the top will enable them to be crossed without exceeding the limit cf 1 in 20; then the most suitable sites for bridges are roughly fixed, and after these observations are taken, the bridle-path is levelled in to the best of the tracer's ability and judgment. On moderately flat ground, when it is certain all the slopes are within 1 in 20, the instrument need not be used, but the line is ranged as straight as possible, the ground to a sufficient width on either side is cleared, and the side ditches are staked out and excavated at once, enclosing the full width of the road between them. It has been customary in Canara to widen the 3-feet trace to the width of 12 feet the first season, as doing so permits pack-bullocks or even a single cart to pass along. The surface of the road inclines outwards slightly to let the water run off, and no drain is allowed to be put on the inner side. There is, however, a cheek or intercepting channel, 18 inches broad and deep, cut some 30 feet above the road, discharging across it at convenient spots.

The reader cannot fail to perceive that, under such circumstances as those just described, an enormous amount of labour is required, merely to clear the track for the observer. Consequently the progress must evidently be slow; the state of the ground to be gone over leaves, however, no alternative, because the works have to be set out, approximately, step by step.

This is not always the case, and very often, indeed, all that we require in surveying through such countries is the length from point to point where a line of survey bends. Very frequently this cutting of tracks may be avoided in hilly or undulating ground by having recourse to a little field-work trigonometry, where we meet with some slight clearing on high grounds.

Great loss of time, to say nothing of waste of labour, in cutting tracks, which consumes a wonderful amount of hard work, might be saved by adopting the application of some of the problems, which we have pointed out in a former chapter: not only would there be a saving in both of the above respects, but more accurate results would be obtained; for it is needless to observe that chaining under the conditions above described is never particularly accurate, unless we are actually setting out work.

As observed above, nothing but length from point to point is required; we have no offsetting, no fencing, no division of property; the land is mere waste; a stream in a hollow is all we may expect to find; very often indeed, we admit not always, the measurement of a short line, with one or two instrumental observations, and one or two short calculations, would in one hour give all we require.

By the ordinary way of proceeding, that is chaining chain by chain, the work occupies at least a whole day, of trying work to the surveyor, and very distressing labour to his men, utterly without necessity.

It is only after experience, under such conditions, that the engineering surveyor becomes really and practically acquainted with what we have just described; only a very faint notion can be given by description; we would, however, advise the reader to think over our suggestions.

CHAPTER IX.

TRAVERSE SURVEYING.

DEFINITION OF TRAVERSE SURVEYING—ACCURACY OF THE SYSTEM—EXAMPLES OF A TRAVERSE, AND OF PLOTTING BY TABLES.

TRAVERSE SURVEYING is a term applied where we adopt such a system as that shown at fig. 49.

When the angles and sides of any polygon, or many-sided figure, are measured in this manner, it is called a traverse; it is a system of surveying, which is in distinction, and we might almost say in opposition, to surveying by a system of triangles, into which the area to be surveyed is then cut up.

Strictly speaking, however, a traverse survey should be plotted by Traverse Tables, which are nothing more or less than multiples of the natural sines and cosines.

If we take the figure shown at 49, or any other whatever in any way alike, and draw verticals and horizontals, through the points 1, 2, 3, 4, 5, &c., we shall describe so many sines and cosines to each of the angles made by the chain-lines with the magnetic and with the East and West; the sines will be, as it were, portions of the magnetic north and south line passing through the station, and the cosines will be those portions of the east and west lines intercepted between the station and the line or vertical dropped from the next station.

These lines are called northings and southings and eastings and westings, the former being the sines and the latter the cosines.

In any figure whatever, regular or irregular, as ABCD in fig. 51, or A, *h*, *k*, *l*, *m*, C, *e*, *f*, &c., the southings are equal to the northings, and the eastings are equal to the westings; that is to say, that in going round it, we go as far north as we do south, and as far east as we do west; the circuit of the circle, or of the square, as well as of the above very irregular polygon, are sufficient to prove this.

In fig. 52, let ABCE be a portion of a regular octagon, which we propose to traverse.

Let AN be the magnetic north; zero, on the horizontal limb of the theodolite, is made to coincide exactly with the needle; in the next place the angle NAB is taken, which will be 22° 30′; 90° minus 22° 30′, equal to 67° 30′, equal to the angle BAF, to which BF is the sine or departure, and AF the cosine or latitude.

Now in the regular octagon, each of the angles at the circumference, that is the angles A, B, C, &c., is equal to 135°; the intersecting angles at B equal to 360°, are made up of ABD equal to 180°, plus ABC equal to 135°, and DBC, which will be equal to 45°. It will be the same thing of course at C, and E, &c., as in the regular octagon all the angles at the circumference are equal to each other.

We will now return to the theodolite, which we have left all clamped, and reading 22° 30′; the length AB being measured, the instrument is to be removed to station B, and there set up and levelled. The instrument being correctly placed at B, we now bring the reading 22° 30′, or rather the opposite reading on the limb, to bear exactly on point A, where a pole is supposed to be held up, care however being taken that the intersection of the crosshairs shall be exactly on the foot of the pole, whilst the vernier, as last fixed on the limb, remains undisturbed. We have already explained how this is effected.

We now bring the instrument to bear on C; the reading will be 247° 30′. The length BC being measured, the instrument is removed to C, where it is to be set up. The reading on the limb here, after the vernier plate has been turned from B round to E, will be 112° 30′.

Let it now be observed that the reading at B was 247° 30′; this deducted from 270° leaves 22° 30′, for the angle CBL, of which CL is the sine or departure in the tables,* and BL the cosine, or the latitude; the reading at C was 112° 30′, deducting this from 180°, leaves 67° 30′, of which LE is the sine or departure, and LC the cosine or latitude.

As a general rule, when the reading is less than 90°, subtract the reading on the theodolite from 90°, which will leave the angle required. When the reading on the instrument exceeds 90°, and less than 180°, subtract the reading from 180°, which will give the angle required; when exceeding 180°, and less than 270°, subtract the reading from 270°; and in the like manner, when the reading is above 270° and under 360°, subtract from 360°, and the remainder will give the angle required.

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* See the Traverse Tables in the 'Engineer's, Mining Surveyor's, and Contractor's Field Book.' (Lockwood and Co.)

In the practice of traverse surveying we always make the reading 5′, 10′, or 15′, &c., according to convenience, by moving the poles, or making our marks on walls, &c., a little to the right or left; this will be found a great practical advantage, inasmuch as it does away with all fractions of minutes, and increases the clearness of reading—a matter of the greatest importance in traverse surveying, for the special purposes we are now considering. It is to be observed that in the usual practice of traverse surveying, we measure the sides and angles round any polygonal figure, regular or irregular, and that in doing so we go as far north as we do south, and as far east as we do west, and that, consequently, the 'southings' are equal to the 'northings,' and that 'eastings' are equal to the 'westings.'

Now the differences of latitudes, or the northings and southings of any line, are the distances that the ends of lines measured round any polygon are north or south of the other ends.

The 'eastings' or 'westings,' or departures of any lines, are the perpendicular distances from one end of the lines to a meridian passing through the other end, the meridians being parallel lines supposed to pass through every station on a survey.

In any polygon, regular or irregular, the sum of all the interior angles is equal to twice as many right angles as the figure has sides, less four right angles. As observed above, and as may be seen by referring to the figure 52, whether we consider the regular octagon or the circle in going round the polygon, we go as far north as south, and as far east as west; therefore, when we reduce the northings and southings of all the lines from the Tables of Difference of Latitude, and, similarly, when we reduce the eastings and westings of all the lines from the Tables of Departures, we at once have proof of the accuracy of the work, since the northings will be equal to the southings and the eastings equal to the westings, if the chaining has been correctly done.

In the same manner, we shall have proof of the angles having been correctly measured, because all the interior angles of the polygon will be equal to twice as many right angles as the figure has sides, less four right angles, or 360°, if the theodolite has been correctly used. There will, however, generally be some two or three minutes' difference, even with the most careful work, unless some particular plan be adopted, such as that which has been mentioned above, of making the readings 5′, 10′, or 15′, &c., by making our marks accordingly. In the description of work to which we have been more particularly referring, a difference of two or three minutes might be of considerable importance; at least for a working survey amongst buildings we should object to it, and the more so that it may be avoided; but in country surveying, or where looking for such minute accuracy would be loss of time, it is usual to divide the difference or error over the whole work.

As to the care necessary for town-land surveys, we will only point out that the mistake of a foot may be of far greater importance than a foot error in a cutting or embankment on an ordinary section, for in this last case it would only involve some difference as to a greater or less quantity of earthwork; but, serious as such a blunder would be, it would be trifling compared to the setting out works, so that any portion of them might fall a foot within instead of outside of a building.

The engineer who has had to set out works through ground thickly covered with buildings, knows all the importance of a correct plan for such purposes.

It is very often by ground plans alone that the lines of working plans are determined—often, indeed, there are no other means of doing it; and not only important and often very expensive working drawings are got out entirely according to surveys, and become valueless if these surveys or plans are incorrect, but very great difficulties arise otherwise. Some considerable length of curve, or straight line, may be laid down on a plan drawn to a large working scale, and properties may be purchased in portions only, and not consecutively along the line, because there may be some cause of delay; indeed, this is a circumstance constantly arising. The works may thus be set out on the ground, and actually commenced, under the guidance of plans only; but if the plans (we mean the *ground-plans*, and not the working drawings) are incorrect, then the lines will have been incorrectly set out on the ground, and very serious consequences may result. The lines may be thus laid out so as to intersect buildings which it was not contemplated to touch, and which we may not even have power to interfere with. When a mass of buildings intervenes between works commenced in two different places along a line, particularly if on a curve, it is often very difficult to check, satisfactorily, work set out from ground-plans only. This kind of operation is, of course, very different to setting-out work in the open country; but even here, when we are setting-out heavy works (interfering with rivers, for instance), errors, arising from the ground-plans being wrong, may be very awkward to rectify, and may involve that which was never contemplated, to say nothing of all the trouble and anxiety which are sure to be incurred, more particularly by the unhappy surveyor himself. It is worth while to enquire whether all such mischances may not, generally, be avoided almost entirely.

We believe that, very often, it is the ordinary system of plotting which is at fault. If the ground is well traversed, or triangulated with a good theodolite, and the lines carefully chained, this part of the work must be satisfactory; but we do not consider as equally satisfactory the means usually employed for laying down the direction of the lines on paper—lines that may be from one foot to two or three feet in length, and perhaps ten or twelve feet apart on the plan; we mean more particularly as regards the angles, and not the lengths of the lines, which merely depends upon carefully using a good scale.

Unless when we set off angles by means of chords and beam-compasses, the protraction of angles is done by means of the protractor, perfect enough within certain limits, as we may observe also of the large parallels used for carrying from station to station the lines laid down with the protractor. For all ordinary purposes this is satisfactory, though far more troublesome than a more simple way of doing the work; for important surveys, plotted to a large scale, for the construction of works, we are satisfied that better means, more simple, and much easier, may be adopted, and which, besides a little simple calculation, require nothing but a straight edge and a good set square. With the exception of a few very short additions, the work is done entirely by tables; exactly the same amount of accuracy may be obtained as in plotting the levels of a section; every engineering surveyor will admit, that this is hardly to be obtained by the usual mode of plotting surveys.

EXAMPLES OF A TRAVERSE, AND OF PLOTTING BY TABLES.

The sketch of a plan, fig. 52*a*, shows a traverse run by the banks of a river: A, B, C, D, &c. are the angles by means of which the work is reduced and plotted, in combination with the length of the chain-lines, which are shown by full straight lines, on which the length of chainage is entered.

We have already explained how the notation of each of these angles is obtained from the field notes. At A, for instance, the reading of the theodolite was 50°, which deducted from 90° gave 40°; at B, by subtraction, we get 80°; and similarly, right through the figure, by deducting the theodolite reading from 90°, 180°, 270°, or 360°, we get each of the angles A, B, C, D, &c. This has been fully gone into under the head of 'Practical Examples of Surveying with the Theodolite,' as also in what we have already written in this chapter.

Having booked all the angles and lengths in the following manner:—

Angles	Length of Course	Feet
A=40°	0′	1,000
B=80°	0′	900
C=35°	20′	820
D=25°	10′	1,420
E=70°	40′	1,010
F=43°	20′	1,140
G=50°	50′	2,030
H=30°	0′	820
I=85°	45′	1,745

we may enter the Traverse Tables already referred to,* and from which we obtain all our data for plotting, without any further trouble than the moving of a decimal point to the right or left.

We have, first, the angle A equal to 40°, and a chainage of 1,000 feet. At p. 104, we have Table of Latitudes, or Horizontal Distances for Differences of Level for 40° and upwards, up to 41°, and for 10, 20, 30, &c. up to 100 feet; at p. 105, we have a similar Table of Departures, or Differences of Level. At present we have only to do with the Latitudes and Departures, as the Horizontal Distances &c., and the Differences of Levels, refer to plotting sections when the levels have been taken by angles of inclination. It will be seen, presently, that in plotting a traverse by means of the tables, it is convenient to have the other application of such tables in view.

We now proceed with the work: for 40°, and under column 100, p. 104, we have 76·604 for the latitude due to 100 feet; then, if we remove the decimal point one figure to our right, we shall have 766·04 equals the latitude for 1,000 feet and 40°. This length of 766 feet is shown at A I on the plane of latitude at the base of the survey.

We now want the departure, or vertical; at p. 105, corresponding to 40°, and under column '100 feet,' we have 64·280. Removing, in the same manner as above, the decimal point one figure to the right, we have 642·8 (which we shall call 643), which will give I B; and a line drawn from A to B will be exactly 1,000 feet long, according to scale, at an angle of 40° with the plane of latitude at the base of the traverse. The next angle is B, equal to 80°, the chainage being 900 feet; at p. 43, and commencing at the bottom of the page, we have for 80°, and for 90 feet, 15·628 for latitude, and removing the decimal point one figure to our right, we have it for 900 feet, equal to 156·28 feet. Similarly in the p. 42, beginning again at the bottom of the page, for departure for 80° and 90 feet, we have 88·633, and therefore 886 feet for 900 feet; 156 is shown at B*b*, and 886 at *b*C.

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* 'The Engineer's, Mining Surveyor's, and Contractor's Field Book,' second edition. (Lockwood and Co., 7 Stationers' Hall Court, Ludgate Hill.)

Our next angle is 35° 20′, and the chainage is 820 feet. At pp. 94 and 95, we have the latitudes and departures commencing from the top of the pages; on the fifth line of the latitude page and under column 80, we have 65·264; then by removing the decimal point one figure to the right as before, we get 652·64 for 800 feet, and for 20 feet we have 16·316, and therefore 652·64 + 16·316 = 668·95, or 669 feet for C*c*; at p. 95, beginning from the top, we have for departures, 46·266 under column 80 feet, which will give 462·66 for 800 feet, and for 20 feet we get 11·567, which, added to the last quantity, gives 474·227 feet for the departure *c*D.

For angle D we have 25° 10′ and for chainage we have 1420; at p. 74 we have the latitudes, and at p. 75 we have the departures, beginning in each case from the top of the page.

For latitudes, we have for 100 feet, 90·507	=	905·07	for 1000 feet
And for 40 feet, we have 36·203 feet .	=	362·03	„ 400 „
And for 20 feet, we have		18·101	„ 20 „
		1285·201	„ 1420 „

and therefore for D*d* we have 1285 feet.

At p. 75, beginning at top, we have for departures,

		Feet	
For 100 feet 42·525	=	425·25	for 1000 feet
And for 40 feet 17·010	=	170·10	„ 400 „
And we have		8·505	„ 20 „
		603·855	„ 1420 „

Neglecting decimals, we thus have 604 feet for *d*E.

For the next angle E we have 70° 40′, and chainage 1010; at p. 63, beginning from the bottom, we have for latitudes,

		Feet	
For 100 feet 33·106	=	331·06	for 1000 feet
And we have		3·311	„ 10 „
		334·371	„ 1010 „

or 334 feet for E*e*.

At p. 62, beginning from the bottom, we have for departures,

	Feet			
For 100 feet 94·361 . . . . . =	943·61	for	1000	feet
And we have	9·436	„	10	„
	953·046	„	1010	„

or 953 for *e* F.

We have now angle F equal to 43° 20′ and chainage 1140; at p. 110, beginning from the top, our angle being under 45°, we have for latitudes,

	Feet			
For 100 feet 72·737 . . . . . =	727·37	for	1000	feet
And	72·73	„	100	„
And	29·095	„	40	„
	829·195	„	1140	„

or 829 for F*f*.

At p. 111 we find the departures, and we have

	Feet			
For 100 feet 68·624 . . . . . =	686·24	for	1000	feet
And	68·62	„	100	„
And	27·45	„	40	„
	782·31	„	1140	„

or 782 feet for *f* G.

For angle G we have 50° 15′ and 2030 feet for chainage. The angle being above 45° we shall have to begin from the bottom of the page.

At p. 103, beginning thus at bottom, we have for latitudes,

	Feet			
For 20 feet 12·789 . . . . . =	1278·9	for	2000	feet
And	19·183	„	30	„
	1298·083	„	2030	„

or 1298 for G*g*.

At p. 102, beginning at bottom, we have for departures,

	Feet			
For 20 feet 15·377 . . . . . =	1537·7	for	2000	feet
And	23·065	„	30	„
	1560·765	„	2030	„

or 1561 for *g* H.

For the angle H we have 30° and 820 feet for chainage, and at p. 84 we have the latitudes, and at p. 85 the departures, in both, working from the top; for latitudes we have

	Feet			
For 80 feet 69·282 . . . . . =	692·82	for	800	feet
And	17·32	„	20	„
	710·14	„	820	„

or 710 feet for H*h*.

In the same manner we get 410 for *h* I.

For the angle I we have 85° 45′ and for chainage 1745 feet.

At p. 33, beginning from the bottom, we have for latitudes,

		Feet			
For 100 feet 7·411	=	74·11	for	1000	feet
For 70 feet 5·188	=	51·88	„	700	„
And		2·964	„	40	„
And for 50 feet 3·750	=	0·375	„	5	„
		129·329	„	1745	„

or 129 feet for I *i*.

At p. 32, beginning from the bottom, we have the departures,

		Feet			
For 100 feet 99·725	=	997·25	for	1000	feet
For 70 feet 69·807	=	698·07	„	700	„
And		39·89	„	40	„
And for 50 feet 49·862	=	4·98	„	5	„
		1740·19	„	1745	„

or 1740 feet for *i* K, which terminates the work.

It will be evident that all the departures may be plotted from the plane of latitude in the same manner as we plot a section from a datum line, and similarly that were it more convenient the latitudes might all be plotted from the plane of the meridian.

It will be seen that the departure III D is made up of 643 + 886 + 474 = 2003, and that IV E = III D − 604 = 1399, and that we shall have constantly plus and minus just as we have rise and fall in a section.

Before commencing to plot an extensive traverse, we plot to a *very* small scale with a protractor, this is very quickly done, and answers the purpose of a guide, it being well to remember that the departures are all sines of the angles and that the latitudes are all cosines.

The observations we have made in previous pages, as to the northings being equal to the southings, and the eastings to the westings, as also that with regard to the interior angles of the polygon, apply only to those traverses which consist of a complete circuit of any polygon.

CHAPTER X.

HARBOUR AND COAST SURVEYING.

OBSERVATIONS OFF SHORE—SETTING OUT BASES—TAKING SOUNDINGS—TIDAL CURRENTS—REDUCING SOUNDINGS—TIDAL OBSERVATIONS—TESTING HOLDING GROUND.

THE following are amongst the requirements of a good harbour:—Easy access and facilities for working in or out. Shelter and security for vessels to ride at anchor, and without danger of their being driven one against the other; as large an area of deep water as can be obtained at the minimum cost; a good beaching ground for disabled vessels; good holding ground, which requires sufficient tenacity in the soil at the bottom of the harbour to bring up a vessel entering the harbour when the wind is blowing hard.

In our survey, therefore, we require a plan of the coast, information as to prevailing winds, as to the depths of water all over the proposed site of the works, the nature of the ground and the set of currents and tides, and the rise and fall of the latter at spring and neap tides; we also have to show the areas of water at various depths.

We must also examine the nature of the materials on the ground, as, for instance, stone in the cliffs; its qualities; how much bearing there is, that is how much earth there is to be taken off before we can get at it, as this is often an important element of cost; we must obtain information as to materials in the neighbourhood.

As regards stone we must examine whether it is sandstone, limestone, basalt, granite, &c.; how it blasts and quarries; how it bears the action of the sea; whether it is laminated. We must look to the shingle and sand for making concrete, and béton blocks. We must ascertain what portions of the holding ground are good or bad, and what area we can have of the former, and how much of the latter may be improved by breaking-up or removing boulders, &c.; how much we have of clay, sand, or gravel bottom.

One of our first operations will be, probably, to make a survey of the outline of the coast; this may be done in the manner we have explained as regards ordinary surveying; we should, however, keep in mind the importance of our principal stations being points for observation out at sea; unless indeed we have very lofty cliffs, and even then we must remember that the lines on the cliffs will require connecting with the lines on the foreshore.

Many of these lines may be measured by observation and calculation, which on coast surveys of any extent saves an immense deal of laborious chaining. The importance of stations on the coast must not be underrated; some slight error, apparently quite venal on the land, may occasion very grave errors when observations are taken on such stations at any distance out at sea.

When our work lies by a large town, we should carefully determine the position of such principal buildings as may be seen out at sea; it is by no means always safe to trust to existing maps on such subjects. To check such a map, it is very simple to measure a short base on the highest convenient spot of ground, and take a few observations on the buildings from both ends of the base and from the centre of it; a few calculations such as those we have already explained under the head of 'Practical Trigonometry' will soon settle the matter. When this is not convenient, it is a short affair to traverse from one building to the other.

We may now come to the matter of taking observations at sea: for this purpose we must have certain bases accurately measured, and by means of these and observations made with the sextant, or box sextant, we determine the position of any spot off the shore where an angle has been taken.

Where the shore is at all flat, that is to say where we have not very high abrupt cliffs, we may set out a base as AB, fig. 53.

It is of the greatest importance that the position of A and B should be accurately determined on the plan, or the positions of 1, 2, 3, &c., where observations are made off the shore, or some two or three miles out at sea, will all be wrong.

This point settled, we may set off at A, a line at right angles to AB, that is A*a*, but in our figure A*a* is a very great deal too short.

At A*a* we require poles to be set up, by means of which the man at the oars may keep himself on the line A, 1, 2, 3, 4, &c. Now we shall require to see these poles a couple of miles out at sea, perhaps more; we want something substantial and plainly apparent a long way off. Fig. 53*a* is the top of a stout pole, about 15 feet high; *a*, *b*, *c*, is a bent wire with a ring at either end *a*, and *c*; to this a red and white flag is fastened; however little wind there may be, it is almost always plainly visible. Sometimes, however, we may be going in the eye of the wind, and then the flag will be barely discernible every now and then. A piece of board, *d*, about 2½ feet long, may be nailed up to the pole, painted red and white; or, if we are in a hurry about the matter, one half may be rubbed over with chalk, and the other with black lead.

Fig. 54 is another description of pole top, which explains itself.

At fig. 55 we give that which we prefer; *a*, *b*, *c*, are three stout iron wires, jointed together at A, where they are fixed through a hole to a spike in the top of the pole; to these are secured three red and white triangular flags made of bunting, each of which is tacked down at the bottom to the flag-pole. These we have always found visible in any weather, and at very great distances; let it be remembered that the more apparent these flagtops are, the more easily we get into line and take our observations.

We may now say a few words about buoys. Sir Edward Belcher recommends the following:

A cask of 32 gallons is furnished with double staves, and of greater width at bung and opposite, as well as double heads. Holes are bored through the bung and opposite staves to admit of the passage of a spar of 3½ inches diameter. This spar, previously well parcelled and tarred, is driven firmly home; cleated to prevent its working out, and caulked round the cleating. Three feet project on the longer end, and none on the smaller; the larger end is furnished with iron for a top-mast, which is 22 feet in length. Close to the cask, on the under side, a thimble is secured, through which the mooring cable passes, as well as one similar down at the lower end of the spar, to prevent chafe. Ballast equal to 2 cwt. is attached at three fathoms below the cask; they are moored taut in the line of the stream, have full-sized bunting flags, and are found to stand bad weather well, and maintain an erect position in very strong currents and tides.

Another description of buoy may be constructed, as at figs. 56 and 57; they may be made entirely out of a 3-inch plank; about 3 feet deep and 2 feet square at top; as nothing but a saw, a hammer, and a few nails are required to make them, they are very readily manufactured. On these we mount a flag-pole such as we have shown at fig. 55.

We now return to fig. 53, and suppose flag-poles set up at

B and A, as also *a*, which shall be plainly visible, and not mistaken for other objects.

We may now consider ourselves in our boat, with a man, or two men, if necessary, at the oars, and another for taking soundings. We are provided with our box-sextant, our field-glasses, a note-book, ruled in columns, and a couple of pencils, in case of one going overboard.

The man at the oars keeps himself in line by means of the poles at A, *a*, and ceases rowing when we tell him; he then brings himself exactly on the line, whilst with the sextant we take the angle A1B; the other man takes the depth water with a sounding line. Both observations are booked in their proper columns, and the hour in a third column. The boatman rows on about eleven strokes, when we take another sounding, but no sextant observation; two more soundings are taken in the same manner.

The next time we take an angle A2B, sounding and time; and so we proceed as far as we judge necessary.

The following tablet explains the calculations which give the distances A1, A2, A3, A4, &c.:—

No. of the observation	Angle	Natural Cotangent		Length of base AB Feet	Feet
1	60,°10′	0·57348	×	1000	573·48
2	49,5	0·86674	×	„	866·74
3	40,10	1·1847	×	„	1184·7
7	20,15	2·7106	×	„	2710·6
9	17,23	3·1942	×	„	3194·3

The last column gives the distances of the stations 1, 2, 3, &c. (when instrumental observations have been taken) from the point A.

Observe now the points *b* and *b′*; on a preconcerted signal being given from the boat, an assistant removes the two poles from A and *a*, to *b* and *b′*, which have been previously set out, so that the length of base, *b*B, is also known.

We now row towards shore, taking the observations, *b* 1 B, *b* 2 B, *b* 3 B, &c., just the same as we did on the last line.

Several similar lines may be set out from base BA, until the base becomes too short to be trustworthy. We obviate this by turning the sextant upside down, when A will become B, and B will become A, or may be made to answer the same purpose, which will do as well.

Or we may set out the line A′B, and the lines AC, AD, EF, EG, in the same manner, but here we have no right angle.

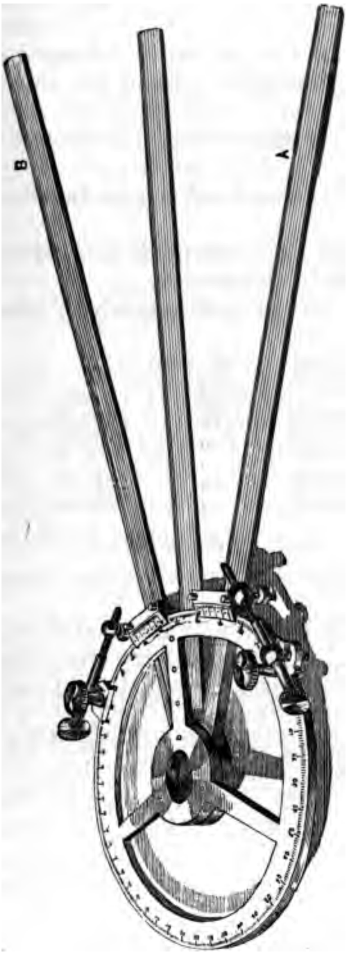
But the calculation is simple enough, being merely this; fig. 58:—

As the sine of C is to AB,
So is the sine of A to BC.

As long as the angle A remains constant, which is the case as long as we keep on one line of soundings, and AB remains the same, we have

$$\frac{\text{Sine of A} \times \text{AB}}{\text{Sine of C}} \text{ equal to the lengths required.}$$

Having once multiplied the sine of A by the side AB, we have only to divide by the sine of each angle of observation to obtain BC, which set off from B, with the beam compasses, fixes the point C.



It is thus we obtain the points 1, 2, 3, in fig. 59; figs. 60 and 61 are given to show the difference between the two modes of calculation, by cotangents in the one case and sines in the other.

The manner in which the lines of soundings are completed, are shown as clearly as they can be explained in figs. 53 and 62.

The angles may be set out by means of the station pointer shown herewith, but we consider it much more troublesome; it is used in the same manner as a protractor.

The object of taking the time when the soundings are taken, is to reduce them to low-water spring-tides. For this purpose there should be a tide gauge, which an assistant should be kept observing. It is his business to note the rise and fall of the tide on this gauge, and to watch also the hours and minutes of the rise and fall.

The depth of the soundings should be taken with the hand lead chain, such as that made by Elliott Brothers. It is divided into feet and short links. At the end of the chain is a leaden weight, about ten pounds; it is of a long conical shape, with a hollow at the bottom which is filled with tallow, to which sand and small gravelly soil will stick. When the lead strikes against rock it will be bruised by the blow. If it is allowed to drag, and strikes against rocks or boulders, we shall know it by the jerks given to the chain, and it will be found cut when pulled up. Sextant observations should be made at spots where this occurs, as in such places the diver will be required to make particular observations.

The lead must not, however, be allowed to drag too loosely, or it will be apt to get entangled among the rocks, and perhaps stick fast.

At fig. 63 we illustrate how the diver's track is shown on the survey.

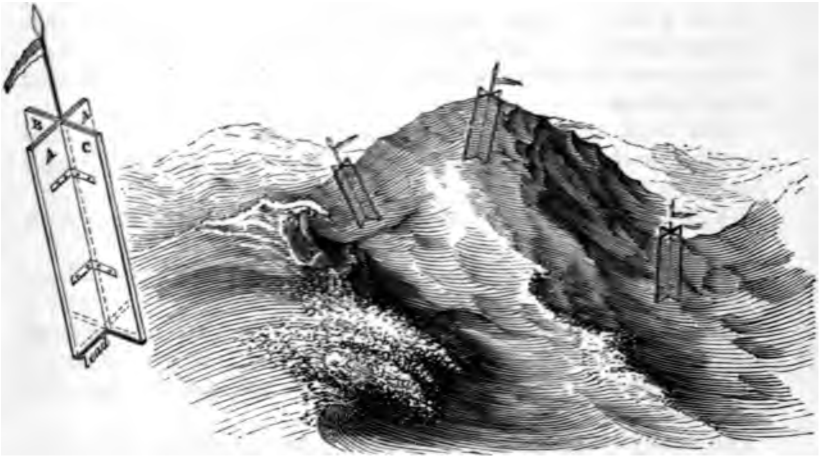
We take sextant observations at each of the spots where circles are shown.

The following notes made by Mr. Joseph Potts, Assoc. Inst. C.E., a friend and late pupil of the author, give a sound practical method of observing the set and velocity of tidal currents.

In many engineering works, such as the improvement of harbours and tidal rivers, construction of docks, reclamation of land from the sea, and the determination of the position of outfalls for sewers, the determining of the set and rate of the tidal current is of the greatest importance, as on this point, and the obvious deductions therefrom, will the success or failure of the project (whatever it may happen to be) to a very great extent depend.

Proceeding, then, to the elucidation of our subject, we will first of all consider the float, the course or path of which is our principal concern. The float should be possessed of the following properties. With the greatest available depth and hold of water, it should have the least possible projection above the surface, and at the same time be observable from the greatest distance. These slightly anomalous conditions are, to a certain extent, reconciled in the one we have been accustomed to use, which is represented in the woodcut in the next page, and may be described as follows:—

Three pieces of teakwood, A, B, and C, are fastened together by eight pieces of L-shaped iron, which is best done by first riveting four of the irons to the piece marked C, the other four to B; then putting C and B on their places on A, and riveting the whole together in the form of a cross, 3 feet deep and 16 inches across either of the arms. A piece of rod iron, about ⅜th inch diameter and 20 inches long, is then driven 5 or 6 inches into the centre; at the top is fastened a small flag (half red, half white), about 10 inches long, tapering from 3 to 1 inch deep at the point; above this, again, is a piece of tin, shaped as in the illustration; and, finally, a piece of sheet-lead, weighing about 20lbs., is fastened to the bottom. This, in smooth water, will just bring the top of the cross level with the surface; and in a sea-way the top will generally be as much below as above the surface. The small superficies of the rod, tin, and flag offer hardly any obstruction to the wind, and by their means the float can readily be distinguished a thousand yards off, provided we have been careful to observe the direction; then, by watching for the glance of the tin in the rays of the sun, we can easily find the float.



With a float similar to the one just described, one of Captain George's, R.N., double sextants (with which the two angles, subtended by any three objects, may be taken with nearly the same facility as a single angle), and a station pointer, there would be nothing left to desire; but frequently the instruments just named are not at hand, and in their places we have merely a ship's compass and common sextant. Even these, when they can be used together, give very reliable results, as the sextant can be used as a check by taking the angle subtended by the objects to which the magnetic bearings are taken, then, by reducing the number of points between the bearings into degrees, it will at once be seen if the one agrees with the other; for instance, if one object bears N and the other NW, as there are 11° 15′ to each point—and we have four points between our two bearings—

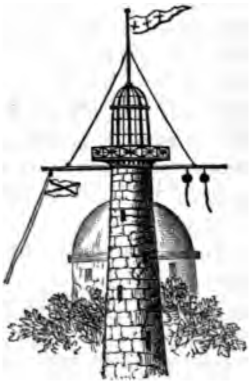
we will have 4 × 11° 15′ = 45°. If, then, the sextant reads 45°, and if the position as obtained from these bearings be marked on the chart, it will be the correct one, provided there has been no local attraction to interfere with the compass.

Generally, however, it will be found that the motion of the boat, if there is any sea to speak of, causes such excessive vibration of the compass card, that any bearings taken by it would be perfectly useless. This, indeed, would in most cases become evident when *trying* to plot the bearings on the chart. To obviate the difficulties arising from using a small boat, we had on one occasion the use of a good-sized tug-steamer, and finding, as we expected, that the compass was perfectly steady, were about to take several bearings when we were informed that the compass had not been adjusted for the attraction of the iron hull and machinery of the steamer, and was therefore of no use whatever. On this account we had to depend entirely on single observations with the sextant; but by only taking these from any two objects that happened to be in line with ourselves to a third at a suitable angular distance, we found the results quite as accurate as if we had had smooth water, and been able to use the compass. For example, in fig. 64, representing a portion of the island and harbour of Bombay, the thick black lines show the course of the float, the fine black lines the direction and line produced from the objects on which the angles were taken, and the dotted lines the angles made with them. The points from which the observations were taken are numbered from 1 to 8. Point No. 1 shows the boat at her anchorage previous to immersing the float; and its position was fixed very accurately by observations with a theodolite from two fixed points on shore; after which, everything being in readiness, the float was put overboard, and the time by watch duly noted. The float was then observed to proceed in a nearly straight line for fully twenty minutes; and, as there was then some danger of losing sight of it, the anchor was lifted, and the boat pulled steadily in the direction the float had taken, keeping one to two hundred yards behind, till the float was observed to change its direction. The boat was then pulled as quickly as possible up to the float, when it was seen that we were in a direct line with the Dolphin Beacon and Oyster Rock fortification. An angle was then taken between this imaginary line and the pilot's signal-pole, the time by watch being again noted.

All these particulars being entered in the note-book (a copy of which will be found at the end of this article), we were then able to fix point No. 2 on the chart by putting a parallel ruler in line with the Dolphin Beacon and Oyster Rock, and making a temporary pencil line along its edge. The zero of a horn protractor was next fixed on the pencil line, and the angle shown on the sextant pricked off, as also the centre of the protractor itself. The parallel ruler was now made to coincide with the angle just pricked off and the point showing the centre of the protractor, and then moved along till in contact with the pilot's signal-pole. A mark was then made at the intersection of this new line with the one first of all laid down. The intersection of these two lines was therefore marked as point No. 2, and a line drawn from point No. 1 to point No. 2 showed the direction and distance traversed by the float. The difference between the times by watch in the note-book gave the exact time taken by the float to travel the distance between points 1 and 2; all these particulars being noticed in the note-book. And we may be pardoned for remarking that in practice the whole operation is very much easier and quicker gone through than it is for us to write, or for the reader to run over the description.

The boat was again pulled after the float, keeping, as before, one to two hundred yards behind; by keeping this distance behind there is little chance of fouling the float, and if the boatmen are up to their work, one minute is ample time to get quite up to it when required. After proceeding in this manner for about 1 hr. 20 min., the float was observed suddenly to change its direction, on which the boat was *at once* pulled up to the spot, and just here we could not in the limited time at our disposal find two sufficiently well-known objects in line, but noticed that the Oyster Rock Fort was just its own breadth clear of the outer bastion of Fort St. George, or what sailors term Oyster Rock, open to the *eastward* of the outer bastion of Fort St. George. This being the best line we could get, an angle was taken between Oyster Rock and the point flag-staff; the time by watch being again taken. When this had been done, and just as the boat was moving from the spot, we noticed that the inner or western sides of the Dolphin Beacon and Cross Island battery were in line; we therefore noted this, because, feeling a little uncertain of point No. 3, we were able to check its position after plotting. To plot point No. 3, the parallel rule was laid on the chart so as to show one breadth of Oyster Rock clear to the eastward of Fort St. George. A line was then drawn along its edge. The zero of the horn protractor being, as before, adjusted to this new line, the angle shown on the sextant being pricked off, and the parallel ruler applied, fixed the position of point No. 3. The parallel ruler being next adjusted to the inner edges of the Dolphin Beacon and Cross Island battery, just intersected point No. 3, thereby proving the accuracy of the work.

When the float had reached point No. 4, it was seen that the corner of a sea-wall was exactly in line with the lofty flag-staff in the bastion of Fort St. George. The angle between this and the point flag-staff was taken with the sextant, marked off with the horn protractor, the time by watch noted, and the position of point No. 4 fixed, as previously described. At point 5, the pilot's signal-pole and the spire of the cathedral were observed to be in line. An angle taken as before to the point flag-staff fixed the position and the time by watch duly noted for the rate. At point 6, we had the lighthouse and the cathedral spire in line, as the point flag-staff was still at a suitable angular distance, and indeed remained so throughout the trial; we took the angle as before, again noting the time by watch. At point 7 the Observatory and lighthouse were in line, and on reference to plate 12, it will be observed that the distance between these two objects is, comparatively speaking, very short, but the nature or form of the objects themselves hindered any inaccuracy that might otherwise have arisen. The lighthouse being columnar and the Observatory having a domed roof, we had only to see that the one bisected the other. The accompanying woodcut will give a better idea of the appearance, as seen from seaward, than any description we could possibly write. The angle being observed and time noted, fixed point No. 7. At point No. 8, the signal-gun tower was seen to be in line with Oyster Rock, and the angle was measured, as before, to the point flag-staff. It was now very near low water, and having followed the float much farther than we actually required, there being moreover a very heavy sea on, we concluded to make the best of our way back again; this was not such an easy matter as might be imagined, the boat being nearly swamped on the way. This circumstance we only mention to give an idea of the weather during which the float trial was made. On reaching the shore, the direction of the wind by compass was noted, and found to be the same as on starting, and had been of nearly equal intensity throughout the whole trial.



When a number of float trials are taken, it is usual to tabulate the results, giving, amongst other particulars, the force and direction of the wind, state of the tide at the times of the observations, &c. From the chart can be measured the distances between the various points traversed by the float in yards. From this, note the time taken by the float in travelling the distance, and by simple calculation the velocity of the current in the spaces between the observations. All these particulars being thus entered enables one to see at a glance the results of observations that may have taken months to make and reduce.

Float Trial, Tuesday , 18 .

Direction of Wind before starting, WSW.
" " on return, SW by W½W.

Date	Angles on Sextant	Name of Object to which Angles were taken	Time of Observation	Name of Objects taken for Line	Remarks
	° ′		h. m.		
	50 28	Boat . .	...	From V. L. sea-wall	To fix position of boat before start
	65 18	" . .	...	From B.B. Co.'s Godown	
	...	... ...	0 5	... ...	Float put overboard
	33 12	Pilot's Signal Pole	1 41	Oyster Rock and Dolphin Beacon	
	34 8	Point Flagstaff	2 53	Oyster Rock and outer bastion of Fort St. George	Oyster Rock one breadth E, and inner sides of Dolphin Beacon and Cross island battery in line
	30 0	" "	3 21	Corner of sea-wall and flagstaff on Fort St. George	
	25 54	" "	3 45	Pilot's signal pole and Cathedral spire	
	25 42	" "	4 01	Lighthouse and Cathedral spire	
	32 09	" "	4 25	Lighthouse and Observatory	Lighthouse intersects centre of dome
	41 04	" "	5 1	Signal-gun tower and Oyster Rock	
	Picked up the Float and returned to the shore.				

The arrows marked in the plate show the directions of the currents as taken from the Admiralty chart; those with feathers denoting flood tides. With respect to the compass card, shown in the plate, it will be observed that each quadrant is divided by 31 lines into 32 divisions called quarter points, the value of each of which in degrees is $32 \div 90^\circ = 2^\circ\ 48'\ 45''$, and the point being equal to 4 of these we have $2^\circ\ 48'\ 45'' \times 4 = 11^\circ\ 15'$, there being 8 points in the quadrant we have

$11^\circ\ 15' \times 8 = 90^\circ$. The ¼ points are shown by short lines, ½ points by lines a little longer, whole points longer still. In nautical phraseology, the divisions are thus described:—The first division to the west or left of north is termed N ¼ W, the next, N ½ W, the next, N ¾ W, and the full point N by W, then N by W ¼ W, N by W ½ W, N by W ¾ W, and NNW. Instead of continuing the reading from NNW, it now apparently begins from NW, although in reality the readings run consecutively thus: NW by N ¾ N, NW by N ½ N, NW by N ¼ N, NW by N; then, NW ¾ N, NW ½ N, NW ¼ N, NW; then, NW ¼ W, NW ½ W, NW ¾ W, NW by W; then, NW by W ¼ W, NW by W ½ W, NW by W ¾ W, and WNW; then, W by N ¾ N, W by N ½ N, W by N ¼ N, and W by N; then, W ¾ N, W ½ N, W ¼ N and W. And so on right round, substituting of course E or S for W or N. We must now apologise for the numerous repetitions and simple details we have been induced to describe, with the object of making this branch of surveying as simple as possible.

From what we have already said about soundings, it will be readily seen that all soundings, at least in all tidal seas, must be reduced to a regular standard. To do this it will be necessary to watch the time of the rise and fall of the tides on a tide pole or gauge. This should be firmly fixed in the most sheltered spot to be obtained, with its zero at such a depth as to ensure its being below the low water at spring tides. When the pole has been properly secured and fixed, set out a level in some safe place corresponding exactly with some full division on the gauge, making a note of the division, or better still, if there is an opportunity, marking near the level set out the exact division on the tide pole to which the level refers. This is a necessary precaution in case the tide pole should be washed away, although it is of course very desirable to take all possible care to avoid not only its being washed away, but even its being in any way disturbed.

An upright tube, open below and above, may be placed in the water, reaching above the high water and below the low water mark, as observed above. In this tube there may be a float carrying an upright rod, or else having attached to it a string which passes upward over a pulley, and is stretched by a weight; the part of the rod or of the string which is outside the tube must carry an index, which shall mark on a vertical scale the rise and fall of the float. By making the tube nearly close below, that is with only one or two small openings, the motion of the waves will have less effect on the float, and the tidal rise and fall may be obtained with considerable accuracy.

The time of high and low water, and the rise and fall of the tide, may be watched in calm weather with sufficient accuracy for some purposes, by observing the surface of the sea rising and falling on a vertical tide pole fixed in open water, but in general the waves will make it more than difficult to observe with anything like accuracy.

The tide pole is of course divided into feet and inches, or better, we think, into feet and tenths, like the levelling staff; of course the exact time of every observation must be taken by watch by some careful assistant stationed to keep account of rise and fall and time in a book systematically ruled out for the purpose.

With regard to the number of observations to be made, we always have them taken at every ten minutes, and we have generally found that the more numerous they are in the course of every hour, the more accurately the work is done.

It may happen to be difficult to determine the moment of the highest and lowest water, either with or without the hollow tide pole, and not on account of the motion of the waves, but because of the water stopping or hanging still near the time of highest and lowest tide, or rising and falling very irregularly; much the same observations may be made as regards the whole rise and fall, more particularly in exposed situations.

If there is a considerable time during which the water neither rises nor falls, note the moment when it ceases to rise, and the moment when it begins to fall, and take the time halfway between these for the time of high water.

Another method is the following: At certain intervals of time near the time of high water, for example every ten minutes, or even every five minutes, let the height of high water be observed, say for half an hour, or an hour, and from the height so observed pick out the highest for the high water, and note the height and the time; and in like manner for low water.

It is not necessary to observe that the correct time for such observations is quite as important as the correct reading of the staff; the assistant therefore to whom this work is confided must necessarily be watchful, or he will be much worse than useless; we have, however, found a steady old sailor able to do this work very satisfactorily when once the matter had been well explained.

The following is perhaps a better mode than the last of dealing with observations thus made every five or ten minutes. Let a number of parallel lines, *ordinates*, be drawn at intervals corresponding to the intervals of observations, and bounded by a line perpendicular to them on one side, *the abscissa*; and on these lines, the ordinates, let the observed heights of the surface be set off from the abscissa, and let a line be drawn through the extremities of the ordinates. This line, if it be tolerably regular, will give the time of high water, and if it be somewhat irregular, it can be smoothed into a curve, and then the time and height of high water read off; and in like manner for low water. The Brunel section paper is exactly the thing for this purpose.

Suppose, for instance, that we have the following observations of the height of water, made every five minutes for an hour.

Time . .	h. m. 0 0	h. m. 0 5	h. m. 0 10	h. m. 0 15	h. m. 0 20	h. m. 0 25	h. m. 0 30	h. m. 0 35	h. m. 0 40	h. m. 0 45	h. m. 0 50	h. m. 0 55	h. m. 0 60
Heights .	ft. in. 6 0	ft. in. 6 6	ft. in. 6 6	ft. in. 6 9	ft. in. 6 10	ft. in. 6 11	ft. in. 7 0	ft. in. 6 11	ft. in. 6 11	ft. in. 6 9	ft. in. 6 5	ft. in. 6 2	ft. in. 5 10

The selection of the greatest height as 7 would give the time of high water as 30 minutes; but the general run of the height would give high water two or three minutes later, as will appear by transferring the above figures to paper in the manner above described, and drawing a line through.

It is a simple thing to draw these lines on the section paper; the divisions on the horizontal line represent hours and minutes, and the divisions in the vertical line give feet and inches, or better, we think, tenths, with paper decimally divided.

It is well to begin a series of tidal observations by observing the height of the water, during the whole day and night, every half hour or every ten minutes, as we have had to do on two or three occasions. If the rise and fall be very irregular, and after stormy weather we have occasionally observed extraordinary irregularities, or if there are any features differing from the ordinary state of things, it will by this means become apparent.

If, for instance, instead of there being two tides in a lunar day, there be one only, or four, both of which cases occur at several places, such peculiarities will be discovered by observations continued during the day and night. If there be a periodical rise and fall of the sea surface, not depending in any obvious way upon the moon, the periods of maximum and minimum should be carefully and exactly observed, in order to determine upon what the rise and fall do depend.

If the tides are tolerably regular it will not be necessary to observe, except for every five or ten minutes near the time of high water and low water, say for one hour, so as to include the exact time near the middle of the hour.

From these observations, by laying down the heights as ordinates and drawing curves, the height and time of high water and of low water will be deducted.

It is desirable to compare the observations of the time of high water and low water with the time of the moon's transit while the observations are going on; for if the tide follow this transit at very irregular intervals, the common modes of observation will probably be of no use, and the time and trouble employed in making them will be lost.

We know of no observations on the subject of tidal registers more clear and simple than those of the late Professor Whewell.

The time of high water at any place on the day of new or full moon is commonly called the *establishment*, because this generally gives the means of knowing the time of high water on any other day. But if the tides are very irregular this is not the case, and then the *establishment* of the place is of no use, or rather there is no establishment proper. If the tides are regular, the establishment may be found from observations made on other days, as well as from those made on the day of new and full moon.

To compare the time of high water with the time of the moon's transit, we must take the moon's transit from the Nautical Table,* and reckon how much the time of high water is after the time of the moon's transit, and put these down as the *lunitidal* intervals. It is not necessary for these purposes to calculate the time of the moon's transit at the place of observation by difference of days. It is sufficient to take the time of the moon's transit at Greenwich, and to *add two minutes for every hour west* longitude of the place; for the moon moving away from the sun so that her distance therefrom is increased 48 minutes in time for every 24 hours, and therefore the transit of the moon is later at every other place by 2 minutes for every hour.

Suppose that we have obtained the observations of high water contained in the following table, we add to them the other columns containing the moon's transit, and the lunitidal intervals calculated therefrom. The alternate transits are interpolated midway between the others, which are given by the table in the Nautical Almanac. The A.M. transit which happens at 0h. 32m. on the 14th day is given in that table as 12h. 32m. P.M., on the 13th the hour of the table being reckoned from noon in the Nautical Almanac.

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* *Nautical Almanac.*

Jan. 1847	Times of High Water	Times of Moon's Transit	Lunitidal Intervals	Jan. 1847	Times of High Water	Times of Moon's Transit	Lunitidal Intervals
	h. m.	h. m.	h. m.		h. m.	h. m.	h. m.
11 A.M.	... ...	(10 33)	... ...	16 A.M.	3 54	2 6	1 48
P.M.	1 7	10 57	2 34	P.M.	4 9	(2 29)	1 40
12 A.M.	1 29	(11 21)	2 32	17 A.M.	4 26	2 52	1 34
P.M.	1 51	11 45	2 30	P.M.	4 43	(3 15)	1 28
13 A.M.	2 11	... ...	2 26	18 A.M.	5 3	3 39	1 24
P.M.	2 29	(0 9)	2 20	P.M.	5 23	(4 3)	1 20
14 A.M.	2 48	0 32	2 16	19 A.M.	5 46	4 27	1 19
P.M.	3 3	(0 55)	2 8	P.M.	6 9	(4 51)	1 18
15 A.M.	3 21	1 19	2 2	20 A.M.	6 34	5 16	1 18
P.M.	3 36	(1 42)	1 54	P.M.	7 1	(5 41)	1 20

In this table we subtract 10 hours 33 minutes, the time of the interpolated moon's transit, from 13 hours 7 minutes equal to 1 hour 7 minutes, the observed time of high water, and we get 2 hours 34 minutes, the lunitidal interval, &c.

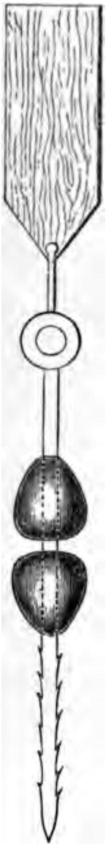
By putting the lunitidal intervals into a curve in the manner already explained, setting off the lunitidal interval belonging to each tide as an ordinate, we ascertain whether the lunitidal intervals follow a regular law, for the line drawn through the extremities of the ordinates will then give a tolerably regular curve.

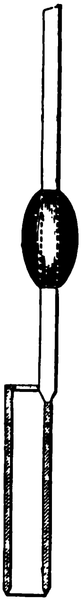
In the above table it may be seen that the term *establishment* is sometimes a rather loose one. The 13th is the day of full moon, for in the course of that day the moon is 12 hours from the sun. The time of high water on that day is A.M. 2h. 11m., and P.M. 2h. 29m., and either of these in the common sense of the term might be called the establishment.

Amongst the methods for testing the ground at the bottom of harbours, as regards the nature of the holding ground, or works for construction, are the following: a diver may drive a bar, pointed at the end, and some four or five feet long, into the ground, to satisfy himself as to its general character, that is, whether it is sand, chalk, loam, or clay; of course if it is rock, the bar will not go in, and it will sometimes be found hard work to penetrate some kinds of clay, whilst in others the bars may be driven some two or three feet or more; when the bars are drawn, the soil attached to them should be carefully examined, and, if necessary, portions should be put aside in little bags, with notes attached as to where and by what means obtained.

Where the bars are driven any depth into the ground, they sometimes can only be drawn by means of a Spanish windlass placed over the gunwale of a ship's launch, or a large boat. In doubtful or suspicious circumstances, buoy ropes are sometimes left attached to the bar, so that persons sent afterwards to examine or confirm work done, may know where to find the situation of the bars.

The following is a naval method of trying the holding ground in a harbour: a ship is anchored in six or seven fathoms at low water spring tides; after veering out to the length of cable thought sufficient to hold in a gale of wind, perhaps a whole or a half cable, or even less, the ship is backed by the paddles; when the cable indicates that the first power of the paddles is felt, the lead is dropped over the side, and watched to see if the anchor starts in consequence of the dragging power applied to the paddles. The experiments ought to be made at a time of slack and smooth water, if the conditions are considered as resembling those of a close harbour.





The plungers, of which we herewith give illustrations, are also used for testing a harbour holding ground; one is an iron bar about 1 inch or 1¼ inch scantling, pointed at one end, and with notches cut lightly into it; it is armed with some sixty or seventy pounds of lead, to force it into the ground; the piece of board at top is attached as a float, to make the plunger descend vertically; it requires a little practice to make it penetrate any depth, but it gives very good indications when fairly used, as the notches in the bar bring up some of the material penetrated. The other plunger represents a hollow cylinder attached to a bar similar to that last-mentioned, armed with lead and with a float; or it may be used without the latter, and may be let down into the water by means of lengthening bars screwed on to the first, in the same manner as boring rods. A little leather or vulcanised india-rubber valve, opening upwards, should be secured to the top of the cylinder, which is, of course, open at the bottom, the edges of which may be made tolerably sharp. This plunger is used for bringing up a plug from the bottom, when it is made to penetrate. A more simple instrument as a plunger may be made by means of about a foot in length of tubing, about 1 inch in diameter, attached by copper wire to one side of a deep sea lead, below which the end of the tube may project about six inches; at the other end of the tube there should be a little valve, like that referred to in the former plunger.

Where any of the above instruments are used, to any extent particularly, that is to say, where they are driven in two or three places close together, so as to show a fair sample of the bottom, observations should be carefully taken to determine the precise spot on the plan.

CHAPTER XI.

WATERWORKS SUPPLY.

RAIN GAUGE—STREAM GAUGING—FORM OF NOTCHES IN OVERFALLS—RULES FOR GAUGING BY OVERFALLS—RAINFALL—NOTES ON GATHERING GROUNDS—VELOCITIES OF STREAMS AND RIVERS.

We have referred in former chapters to the subject of surveys for canals and irrigations. The actual surveys of a large gathering ground are made after the area and contours are ascertained; they are generally made to a very small scale. The geological formations, the state of cultivation, with the rivers and streams, are amongst the principal features we shall have to show on such a survey, besides the position of rain gauges.

It is sometimes requisite to show some of the valleys running parallel to those within the area of watershed proper; this has to be done when, for instance, it is intended to drive a heading through an intermediate hill or ridge, as this may be the means of obtaining a large additional quantity of water.

With regard to river surveys, some of the many observations we have already made apply in the same manner. At fig. 65 we show a system of triangulation for a large river, and two large areas of ground liable to inundation at floods. After the angles have all been carefully taken with the theodolite, and the bases all chained, the remaining sides should be calculated, unless we choose to be satisfied with the mere use of a protractor. On many of the lines shown, sections or soundings will have to be given.

These operations are carried on in the same manner as that we have explained under the head of 'Harbour Surveying;' and may be done on the lines of triangulation.

The most important observations we shall have to make as regards the area of watershed, are as to the geological formation; the state of cultivation, as arable, grass or meadow lands; those that are barren, woody, or consisting of peats; lands from which the waters are appropriated by existing mills or manufactories. All these have generally to be shown on the best maps we can obtain, after corrections have been made. In our own country the Ordnance maps are generally used. The areas as to all the above matters have to be computed.

We shall also have to ascertain the rainfall. At home there is much less difficulty than there used to be on account of the very numerous meteorological observers we have now. We shall have to ascertain the discharge from rivers and streams, and the compensation to be made for withdrawing water from vested interests, such as mills and manufactories.

The rainfall is measured by observations made with the rain gauge,—a simple little instrument with which almost every one is acquainted now-a-days; the use of it is not so much required at home as it used to be, because of the many valuable rainfall tables we have now; a very excellent one, and very copious, will be found in Mr. Beadmore's Hydrology.

Prevailing winds, proximity to the sea, altitude, exposure, or shelter, all influence the quantity of rainfall. All these matters require to be considered in fixing the position of rain gauges.

It is very important that the area of the mouth of the rain gauge should be well defined; in those most carefully made the rim of the mouth is turned in a lathe: this rim should be strong, so as not to be liable to be deformed, and should project inwardly, so as to prevent the rain from splashing over.

When a number of gauges have been established over a large area of ground, it often requires some activity to do justice to the subject; they require visiting often, particularly after sudden rainfalls.

Rain gauges should always be placed in open unsheltered situations; at different altitudes, on extensive areas, and always on the ground; they require considerable watching.

A glass measure to ascertain the depth of rainfall, from the quantity of rain water found in the gauge when examined, is sold with the gauges; this should be carried about in a case, like a telescope.

The erection of notched boards, or overfalls, for measuring the discharge of streams, is often a very important matter. If not done well it had better not be done at all.

We should first look for a favourable spot; this will generally be where there is a straight run of the stream between even banks, and where the bed is level; if we can find a place just below a widening out of the banks forming a kind of basin, this will be exactly the place to be selected. The overfall should be built up out of two-inch planking, made perfectly water-tight, and if of any length, it should have a strong frame to prevent its bending.

A rectangular notch should be cut in the board, of some very exact dimensions in feet, and this notch should not be so narrow in proportion to the stream as to 'wire-draw' it, or cause a great increase of velocity in the approaching stream.

The edges of the notch should be chamfered and made quite smooth, as also a plate of iron which should be carefully inserted at the back; every care should be taken to make all this as even as possible. If the iron plate is omitted, the edges of the notch soon become ragged and uneven.

The depth of the planking should reach from the top of the banks of the stream, right down into its bed, that it may not leak underneath.

The overfall should be fixed square across the stream and so that its centre should correspond with the centre of the current. Sharp, clean-cut trenches should be cut in the banks and bed of the stream to receive the board. Some well-tempered clay or puddle should be ready at hand to trample down by the sides of the board the moment it is dropped into its trench; that is, before the water has had time to accumulate behind it. A rough kind of timber apron should also have been prepared to fit the stream, and as soon as the overfall has been got in, and the clay puddled down, this apron should be fixed before the water begins to overflow, or it will very quickly tear up the puddle and the bed of the stream below.

The cill of the overfall should be high enough to prevent its being submerged when the rains come on; but it should not be raised sufficiently to cause the first floods to overflow the banks. Circumstances only can guide us in considering this matter.

Before setting up the overfall, we should drive a stout post into the bed of the stream and in the centre of the current, some distance above.

After the board has been got safely in, a feather-edged rule, some two or three feet long, divided into tenths and hundredths of a foot, or into inches, should be nailed to the post, and the zero of this rule should be made exactly level with the cill of the overfall. This rule will be the measure of the depth of water at the rule, above the level of the cill.

The triangular, instead of the rectangular form of notch, was introduced by Professor Thomson of Belfast, and the following observations and recommendations are made in favour of its general adoption for gauging the discharge of streams, more particularly in reference to the requirements we now refer to.

The rectangular notch has been experimented on in various countries, at great cost, and by many of the most eminently scientific and practical men, in France and England particularly, the object being to determine the coefficients of formulas necessary for their application in practice. For many purposes they are both suitable and convenient. They are, however, but ill adapted for the measurement of very variable quantities of water, such as commonly occur in gauging small or moderately sized streams; this is particularly the case with streams flowing through meadows or slightly undulating countries, where the banks are shallow, and when the quantity of water flowing past all the year round has to be ascertained.

If the rectangular notch is made wide enough to allow all the flood water to pass through it at all times, which is generally what we are anxious to ascertain, then in dry weather the water runs so shallow over the crest of the overfall, that its indications cannot be so well relied upon. This at least will be the case unless the overfall is set up in seasons of drought.

In the rectangular notches the parallelograms are dissimilar for every varying depth of water, but for the triangular notch the triangles are always similar.

To remove in some degree this objection, gauges for rivers and streams are sometimes formed with a small rectangular notch, cut down below the general level of the crest of the large rectangular notch. This, however, is only where great accuracy is sought for, and will involve rather intricate formulas.

If now, instead of one depression being made for dry weather, and others for larger quantities of water, we use a crest wide enough for use in floods, we may conceive a large number of depressions extending so as to give the crest the appearance of a set of steps of stairs; and if we conceive the number of such steps to become infinitely great, we are led at once to the conception of a triangular instead of a rectangular notch.

The principle of the triangular notch being thus arrived at, it becomes evident that there is no necessity for leaving one side of the notch vertical and the other slanting; but that it may in many cases prove more convenient that both sides should be made slanting with slopes alike; the former arrangement indeed would be very inconvenient.

It is then to be observed, that by the use of the triangular notch, with proper formulas and coefficients, derivable by due attention to theory and experience, quantities of running water, from the smallest to the largest, may be accurately gauged by their flow through the same notch.

The reason of this is obvious, from considering that in the triangular notch, when the quantity flowing is very small, the flow is confined to a small space admitting of accurate measurement; and that the space for the flow of water increases, but still continues such as to admit of accurate measurement by the same formula and coefficient, the depth of water being the only variable quantity.

Further, the ordinary rectangular notch, when applied for gauging rivers, is subject to a serious objection from the difficulty or impossibility of properly taking into account the influence of the bottom of the river on the flow of the water in the stream towards the notch.

If it were practicable to dam up the stream so deep that the water would flow through the notch as if coming from a reservoir of still water, the difficulty would not arise. This is generally what we aim at in setting up overflow notch boards, at least as much as possible; we have, however, often to guard against flooding higher up the stream, where perhaps a public road may cross, and also to the result of heavy freshets, which would be to constantly overflow the dam.

It is, however, very seldom that we can do exactly what we want in practice, and although the bottom of the stream or river may be so far below the crest as to produce but little effect on the flow of the water, when the quantity flowing is small, yet when this is reversed the velocity of approach comes to have a very material influence on the flow of the water, but an influence which is usually difficult to ascertain with satisfactory accuracy.

In the triangular form of notch, the influence of the bottom may be rendered definite, and such as to affect alike (or at least by some law that may be readily determined by experiment) the flow of the water when very small or very great in the same notch.

The method by which Professor Thomson has proposed that this may be effected consists in constructing a floor starting exactly from the vertex of the notch, so as to form a bottom for the channel of approach, both up stream and laterally, which will both be smooth, and will serve as the lower bounding surface of a passage of approach unchanging in form, while increasing in magnitude, at the places at least which are adjacent to the vertex of the notch.

No doubt this would be a very accurate mode of dealing with special cases, but when numerous streams have to be gauged over a wide area of country, it would become very expensive to construct such gauges for every case.

The floor might be either perfectly level, or might consist of two slanting planes, whose intersection would start from the vertex of the notch, and would pass up stream perpendicularly to the direction of the outfall; the two planes slanting upwards from their intersection more gently than the sides of the notch.

The level floor, although theoretically not quite so perfect as the floor with the two slanting planes, would probably be the most convenient arrangement for general practical purposes. Considering all the minor practical difficulties which arise in getting an overfall well set in the streams to be gauged, there is no doubt that the level floor would be the most easily set up. This will be readily admitted by all who have had experience of setting up such dams, and even the level floor would occasion some trouble in a stream of any size.

With reference to the use of the floor, it may be said, in short, that by a due arrangement of the notch and the floor, a discharge orifice and channel of approach may be produced, of which the upper surface of the water being considered as the top of the channel and orifice, the forms will be as little changed as possible, with variations in the depth of water flowing over; much less certainly than in the case of rectangular notches.

Whatever may be the result in this respect, the main object must be to obtain, for a moderate number of triangular notches of different forms, both with and without floors at the passage of approach, the necessary coefficients for the various forms of notchės and approaches selected, and for various depths in any one of them, so as to allow of streams being gauged for practical purposes by means of similarly formed notches and approaches. Whatever form of notch is adopted there can be no doubt that it is very desirable to adopt the like form throughout a series of experimental overfalls, and to make them as much as possible bear the same proportion to the body of the stream.

The utility of the proposed method of gauging will not depend upon a perfectly close agreement of theory with experiments, because a table of experimental coefficients for various depths, or an empirical formula modified from the theoretical one, will serve all general purposes.

There is one very decided and practical simplification in the method of gauging streams introduced by Professor

Thomson, and which has become adopted by many; the quantity of water flowing becomes a function in a form with only one variable, namely, the measured head of water; practically at least it will be so in ordinary cases. In the rectangular notches there are two important variables, the horizontal width and depth of the notch, as well as the head of water; there is frequently also a third variable very difficult to be taken into account, namely the depth from the crest of the notch to the bottom of the channel of approach, which depth must vary in its influence with all the varying ratios between it and the other two quantities of which the flow is a function.

The proposed system of gauging also gives facilities for taking another element into account, which often arises in practice, namely the influence of backwater on the flow of the water on the gauge, when, as frequently occurs in rivers and streams, it is found impracticable to dam up sufficiently high to give a clear overfall, free from the backwater.

For any given ratio of the height of the backwater above the vertex of the notch to the height of headwater above the vertex of the notch, Professor Thomson would anticipate that the quantities flowing would still be, approximately at least, proportional to the square root of the fifth power of the head as before. A set of co-efficients would have to be determined experimentally for different ratios of the height of the head of water to the height of backwater above the vertex of the notch.

Some preliminary experiments were made on a right-angled triangular notch in a vertical plane surface, the sides of the notch making angles of 45° with the horizon, and the flow of water being from a wide and deep pool of quiet water, the fluid thus approaching the notch uninfluenced by any floor or bottom. The experiments were made on quantities of water varying from about 2 to 10 cubic feet per minute, with heads varying from 2 to 4 inches in the right-angled triangular notch.

From them the following formula was derived:

$$Q = 0{\cdot}317 \sqrt[2]{H^5},$$

in which Q is the quantity of water in *cubic feet per minute*; and H the *head in inches* measured vertically from the still water level of the pool down to the vertex of the notch.

The foregoing formula has only been submitted temporarily as being accurate enough for use for ordinary practical purposes, for the measurement of water flowing from notches similar to the one experimented upon, and for quantities limited to nearly the same range as those in the experiments.

In the ordinary practice of stream gauging, to which we now principally refer, the above formula and the application of the right-angled triangular overfall are found exceedingly convenient, as there are in reality no calculations to make when once a table of the square root of the fifth powers has been calculated. Where there is a numerous series of gauges, over an extensive area of country, requiring gauging as often as possible in the course of every twenty-four hours, a very great number of calculations have often to be made in the old and ordinary manner of gauging, where very accurate results are required.

It may, however, be mentioned that to obtain this accuracy anything like literally, it requires some very trustworthy observer to be constantly on the watch at every overfall; a passing shower, more particularly where the stratification causes the action to be rapid, a lump of weeds, or a small branch of a tree which may get temporarily entangled on the crest of the notch, may vitiate gaugings, as far as very great accuracy is concerned, although otherwise made with great care.

Mr. Neville, the eminent authority on hydraulics, makes the following observations on this subject:—

'The disadvantage of the proposed triangular form of depression, if permanent in a dam, would be that the angular point should be at a lower level than the top of a horizontal crest to maintain the same level above, of the water during floods, and therefore the power of the water and head would be reduced at the period when most required for mill power or navigation purposes, that is during dry weather. For drainage purposes the winter level, or that during floods, must evidently be kept down, unless where the banks are steep and along rapids; but these remarks do not apply to dams erected across mill races or streams, where the banks are generally considerably above floods. These remarks refer to occasions for permanent gauging to find the relations of evaporation, absorption, and discharge in given catchment areas.'

We have already explained the construction of overfalls or notched boards for gauging the discharge of streams; we will only again refer to the necessity of their being carefully got into the bed and banks of the streams, that they should be water tight, and with the cill perfectly level. It is unnecessary to observe further that these gauges require watching in order that nothing should occur to cause an escape at the sides or at the bottom of the stream, a circumstance which may be occasioned by heavy floods, unless the subject is carefully looked after.

If we take a board with a notch of any shape whatsoever cut in it, the board will first pen back the water to a certain level, and very soon after the water will fall or flow over the notch with a velocity due to the difference of level between the surface of still water and the centre of the cill of the notch.

The velocity of water flowing through an aperture is taken as equal to that acquired by a heavy body falling in vacuo through a given height equal to the difference of level just above referred to.

The velocity, *per second,* in passing through any unit as a foot or an inch is equal *in terms of such unit* to twice the square root of the force of gravity, and the velocity acquired in falling through any given height is as the square root of the height fallen through.

If we put H for the height in feet, observing that such height refers to the above-mentioned difference of level, and if we put V in similar terms for the velocity acquired in falling through H, and G in the same terms for the force of gravity or height fallen through by a heavy body in one second of time, we shall obtain the following expressions, G in the latitude of London being taken at 16·08 feet,

$$V \text{ per second} = 2\sqrt{16{\cdot}08H} = 8{\cdot}02\sqrt{H}.$$

It is usual, however, according to the most recent experiments, to take this expression as

$$V \text{ per second} = 8{\cdot}03\sqrt{H}.$$

Or, $$V \text{ per minute} = 481{\cdot}8\sqrt{H}.$$

The discharge through any aperture will always be equal to the mean velocity multiplied by the actual sectional area of the escaping fluid, and which sectional area is never equal to that of the aperture.

If they were equal we should have,

$$\text{Discharge per minute} = 481{\cdot}8\,A + \sqrt{H},$$

in which A is put for the area of aperture.

In all cases the co-efficient 481·8 requires modification, and for the apertures now referred to, that is, the overfalls from weirs and notched boards, there is a very considerable modification on account of the parabolic form of the fall of water, besides the friction and the contracted vein.

The issuing water assumes a parabolic form, and the sectional area is two-thirds of the circumscribing rectangle, and putting A for the area of such rectangle, and L the length of the overfall, and C for the co-efficient, we shall have

$$\text{Discharge per minute} = 481{\cdot}8 + L + \tfrac{2}{3}\,A + \sqrt{H} + C.$$

Very numerous experiments make the co-efficient to vary from about ·58 to ·7; therefore 481·8 may vary between 186·3 and 224·8. As an average C is very commonly taken at ·63, so that the

$$\left.\begin{array}{l}\text{Discharge in cubic feet per minute over}\\ \quad\text{every foot in length of an overfall}\end{array}\right\} = 204\sqrt{\mathrm{H}^3}\text{ or }204\mathrm{H}^{\frac{3}{2}}$$

where H is the head *in feet*, or the difference in level from the cill of the notch to the surface of still water above.

And where the head h is taken *in inches*, the co-efficient is very commonly taken at 5·1, when the

$$\left.\begin{array}{l}\text{Discharge in cubic feet per minute}\\ \text{over every foot in length of overfall}\end{array}\right\} = 5\sqrt[2]{h^3}\text{ or }5\,h^{\frac{3}{2}}$$

These co-efficients apply to overfalls of which the outside arrises are chamfered and smooth; if the inner and outer arrises are rounded and smooth the co-efficients will be considerably increased. Mr. Neville, in his invaluable work on hydraulics, has given some lengthy tables of co-efficients, of which it has been rather idly said, 'It seems a waste of time and an attempt to refine where the data are not sufficient for the purpose.' Where accuracy is to be obtained we consider their application indispensable, at the same time that we admit that it involves considerable amounts of calculation, but Mr. Neville does not seem to think very highly of what may be termed *royal roads*, and as regards the data, we very much doubt whether we shall ever have better than those we possess.

A few concise practical remarks on the use of average co-efficients may be acceptable in reference to general purposes.

From the valuable experiments of Poncelet and Lesbros at Metz, we find the co-efficients vary from ·577 for an aperture 8″ by 8″ to ·63 for an opening of 8″ by 4″; the mean value of ten experiments is ·603.

Du Buat's experiments with a notch 18 inches long give ·632 for a mean value, and Brindley and Smeaton's experiments with notches 6 inches wide and from 1 to 6½ inches deep, give from ·571 to ·713, the mean being ·637.

Mr. Ballard's experiments with a board 2 feet long give ·732 for an average co-efficient; but there is reason to believe that the heads were taken on the board itself instead of to the level of still water.

Mr. Blackwell's experiments with an overfall bar, 2 *inches thick* and 10 feet long, give co-efficients varying from ·591 with a depth of about 1 inch to ·781, with a depth of 9 inches, the mean of nineteen experiments being ·723; the velocity of approach in most of the experiments was, however, plainly perceptible.

Where, in the above formulas, we make use of that with co-efficient C, the following tablet, derived from the Kennet and Avon experiments, will be useful :—

Where we seek to make our calculations by shorter and somewhat less accurate results, though sufficiently so for general purposes, we may make use of the following table where the co-efficients in column marked A are given instead of 204 in the formula $204\sqrt{\text{H}^3}$ (H being the head in feet); those in column B will apply instead of 5 in the formula $5\sqrt{h^3}$ (*h* the head being in inches). The description of the overfalls apply to the same experiments as the last :—

Head, from crest to level of still water	Description of Overfall	A	B
Inches			
From 1 to 3	Thin plate 3 feet long	212	5·1
„ 3 to 6		194	4·68
„ 1 to 3	Thin plate 10 feet long	241	5·76
„ 3 to 6		210	5·16
„ 6 to 9		178	4·32
„ 1 to 3	Plank 2″ thick at crest	165	3·96
„ 3 to 6		185	4·44
„ 6 to 9		196	4·62
„ 1 to 3	Ditto 6 feet long	173	4·14
„ 3 to 6		191	4·60
„ 6 to 9		189	4·44
„ 9 to 14		173	4·14
„ 1 to 3	Ditto 10 feet long	167	4·08
„ 3 to 6		191	4·60
„ 6 to 7		180	4·32
„ 9 to 12		172	4·14
„ 1 to 2	Ditto 10 feet long, with wing boards at an angle of 60°	230	5·52
„ 4 to 5		213	5·22
„ 1 to 3	Crest 3 feet wide, 3 feet long, level	147	3·54
„ 3 to 6		150	3·60
„ 6 to 9		153	3·66
„ 1 to 3	Ditto ditto, sloping 1 in 18	175	4·20
„ 3 to 6		152	3·66
„ 6 to 9		160	3·84
„ 1 to 3	Ditto ditto, sloping 1 in 12	165	3·96
„ 3 to 6		158	3·78
„ 6 to 9		163	3·96
„ 3 to 7	Crest 3 feet wide, 6 feet long, level	159	3·72
„ 7 to 12		149	3·60
„ 1 to 5	Ditto, 10 feet long, level	147	3·54
„ 5 to 8		158	3·78
„ 8 to 10		151	3·66

OVERFALLS.

Head, in inches, from crest to level of still water	In Thin Plates		In Planks, 2 inches thick at crest				Crests, 3 feet wide					
	3 feet long	10 feet long	3 feet long	6 feet long	10 feet long	10 feet long, with wing boards at an angle of 60°	3 feet long, level	3 feet long, sloping 1 in 18	3 feet long, sloping 1 in 12	6 feet long, level	10 feet long, level	10 feet long, sloping 1 in 18
1	·677	·809	·467	·459	·435	·754	·452	·545	·467	... ...	·381	·467
2	·675	·803	·509	·561	·585	·675	·482	·546	·533	... ...	·479	·495
3	·630	·642	·563	·597	·569	... ...	·441	·537	·539	·492	... ...	... ...
4	·617	·656	·549	·575	·602	·656	·419	·431	·455	·497	... ...	·515
5	·602	·650	·588	·601	·609	·671	·479	·516	... ...	... ...	·518	... ...
6	·593	... ...	·593	·608	·576	... ...	·501	... ...	·531	·507	·513	·543
7	... ...	... ...	·617	·608	·576	... ...	·488	·513	·527	·497	... ...	... ...
8	... ...	·581	·606	·590	·548	... ...	·470	·491	... ...	... ...	·468	·507
9	... ...	·530	·600	·569	·558	... ...	·476	·492	·498	·480	·486	... ...
10	... ...	... ...	·614	·539	·534	... ...	... ...	... ...	... ...	·465	·455	... ...
12	... ...	... ...	... ...	·525	·534	... ...	... ...	... ...	... ...	·467	... ...	... ...
14	... ...	... ...	... ...	·549	... ...	... ...	... ...	... ...	... ...	... ...	... ...	... ...

The following is a table of *Theoretical* Discharges over 1 foot in length of any overfall in cubic feet *per minute.* The figures, therefore, only require multiplying by the suitable co-efficient from the former of the above two tables and by the length of the overfall to give the actual discharge :—

Head	Discharge	Head	Discharge	Head	Discharge
Inches	Cubic feet	Inches	Cubic feet	Inches	Cubic feet
0·25	0·96	7·75	166·60	19·5	664·94
0·50	2·73	8·	175·73	20·	690·68
0·75	5·02	8·25	182·98	20·5	716·74
1·	7·72	8·50	191·37	21·	743·13
1·25	10·79	8·75	199·87	21·5	769·83
1·50	14·19	9·	208·50	22·	796·83
1·75	17·88	9·25	217·24	22·5	824·15
2·	21·84	9·50	226·11	23·	851·78
2·25	26·06	9·75	235·09	23·5	879·70
2·50	30·52	10·	244·19	24·	907·93
2·75	35·22	10·25	253·41	25·	965·25
3·	40·12	10·50	262·73	26·	1023·75
3·25	45·24	10·75	272·17	27·	1083·38
3·50	50·56	11·	281·72	28·	1144·12
3·75	56·08	11·50	301·15	29·	1205·95
4·	61·78	12·	321·20	30·	1268·86
4·25	67·66	12·50	341 27	31·	1332·83
4·50	73·71	13·	361 95	32·	1396·84
4·75	79·94	13·5	383·03	33·	1463·88
5·	86·33	14·	404·51	34·	1530·92
5·25	92·89	14·5	426·37	35·	1598·95
5·50	99 60	15·	448·61	36·	1667·96
5·75	106·47	15·5	471·23	37·	1737·94
6·	113·49	16·	494·21	38·	1808·88
6·25	120·66	16·5	517·56	39·	1880 75
6·50	127·97	17·	541·26	40·	1953·54
6·75	135·42	17·5	565·32	41·	2027·26
7·	143·02	18·	589·72	42·	2101·88
7·25	150·74	18·5	614 44	43·	2177·39
7·50	158·61	19·	639·53	44·	2253·78

When a weir or overfall extends from side to side of a channel, the contraction is less than when it forms a notch, and the co-efficient sometimes rises to nearly ·7. When the weir or notch extends only one-fourth or less of the width of the channel, the co-efficient may vary from ·58 to ·6.

A gathering ground is a certain area of country which receives and intercepts more or less the amount of rain falling over it; this quantity will therefore generally depend on the geological formation, on the nature of the superficial ground, on the angle of inclination, and on the natural or artificial drainage.

Even a casual examination of gathering grounds from which it is proposed to collect water for the purposes of a town supply requires grave consideration.

Gathering grounds are drained by rivers and tributary streams, and generally those are selected which are surrounded by high grounds and sometimes lofty mountains; it is more particularly in the latter case that gathering grounds are valuable on account of the large amount of rain collected by mountain ridges, provided, however, there is nothing unfavourable about the geological character.

The upper basins of the main tributaries of the River Severn consist of about 130,000 acres, and the summits of the gathering grounds are from 2,500 to 3,000 feet in altitude, and the average annual rainfall is probably not much less than 150 inches; in some parts of Essex the annual rainfall is said to be less than 20 inches.

The depth of rainfall in inches multiplied by the constant 2,323,200 will be equal to the quantity of water in cubic feet per square mile.

Hence the following tablet:—

Cubic Feet per Square Mile according to the Depth of Rainfall

Rainfall	Cubic feet, per square mile	Rainfall	Cubic feet, per square mile
Inches		Inches	
0·100	232,320	0·525	1,219,680
0·125	290,400	0·550	1,277,760
0·150	348,480	0·575	1,335,840
0·175	406,560	0·600	1,393,920
0·200	464,640	0·625	1,452,000
0·225	522,720	0·650	1,510,080
0·250	580,800	0·675	1,568,160
0·275	638,880	0·700	1,626,240
0·300	696,960	0·725	1,684,320
0·325	755,040	0·750	1,742,400
0·375	813,120	0·775	1,800,480
0·400	871,200	0·800	1,858,560
0·425	929,280	0·825	1,916,640
0·450	987,360	0·850	1,974,720
0·475	1,045,440	0·875	2,032,800
0·500	1,103,520	0·900	2,090,880
	1,161,600	0·925	2,148,960
		0·950	2,207,040
		0·975	2,265,120
		1·000	2,323,200

The depth of rainfall multiplied by the constant 3630 will give the quantity of water in cubic feet per square acre.

The variations that may and do constantly occur in the annual depth of rainfall in various parts of Great Britain is partly shown in the following tablets.

For instance, we have the following record for the Longdendale Valley near Manchester, the Rhodes Wood Station

being 520 feet above the level of the sea, and the Woodhead 680 feet above the same level, or 160 feet higher:—

Years	Rhodes Wood. Rainfall in inches	Woodhead. Rainfall in inches
1855	34·49	40·33
1856	49·16	50·89
1857	40·04	46·08
1858	42·77	45·54
1859	46·34	53·35
1860	47·85	53·69
1861	40·22	44·24
1862	47·28	49·63
1863	48·04	53·77
1864	38·50	43·52

MEAN RAINFALL IN THE LAKE DISTRICT.

Place of observation	Level above sea	Number of years of observations	Mean depth of rainfall
	Feet		Inches
Keswick	258	10	59·6
Loweswater	336	10	67·29
Crummock Lake	260	10	84·1
Gatesgarth	290	9	114·7
Eskdale Head	—	7	77·9
Wastdale Head	247	10	101·4
Selside	736	5	73·5
The Hough, Troutbeck	503	10	79·3
Ambleside	190	6	79·6
Seathwaite	—	9	140·5
Stonethwaite	340	7	111·4

LOCH KATRINE DISTRICT.

Situation of gauge	Level above sea	Depth of rainfall		
		1855	1856	1857
	Feet	Inches	Inches	Inches
Bridge of Turk	270	39·0	48·3	54·8
Between Glen Finlas and Glen Ledi	1800	56·1	—	48·3
Glengyle	380	65·5	79·3	91·6
Between Loch Ard and Loch Katrine	1500	74·1	74·2	—
On Slope of Ben Lomond	1800	69·9	81·0	85·5

The following table of average depths of rainfall in the same district shows how very greatly these depths may vary in localities which are at no great distance from each other, and consequently how important it is to study with great attention where the rain gauges should be placed:—

Valley gauges	Height above sea level	Number of years	Mean depth of rainfall
	Feet		Inches
Loch Venekar	275	4	64·7
Bridge of Turk	270	11	60·2
Glengyle	380	11	92·4
Loch Dhu	325	4	91·7

Mountain gauges	Height above sea level	Number of years	Mean depth of rainfall
	Feet		Inches
Loch Drunker	420	—	—
Between Glen Finlas and	1800	10	59·9
Glen Ledi	830	4	86·2
Between Loch Chou and Loch Katrine	1500	10	84·8
On Slope of Ben Lomond	1800	11	91·9

Where the gathering ground from which it is proposed to collect a supply is very extensive, and where the levels vary greatly; where the exposures differ very much and the configuration is very irregular in some places and at others very flat; where there are numerous streams and tributaries; where the geological formations vary at all; where there are sands, clay, gravel, or rock;—under these circumstances the accurate gauging of streams and of rainfall becomes very intricate, and it is frequently difficult to reconcile discrepancies.

Almost always there will be a much heavier rainfall on one side of a chain of hills than on the other. The number of troughs or valleys towards the summit of hills will form catchment basins for clouds, where they will deposit rain, and on mountains where these do not occur, the clouds will often pass on without depositing any of their watery contents.

The amount of rainfall increases generally with the rise of levels, but more rain falls on the flanks of mountains than at their summits, more particularly under the conditions above referred to.

In the West of England it is generally found that after the clouds come over the westerly summits, a large amount of water is caught in the first troughs of a valley; so that at a much lower point on one side of a ridge there may be a heavier rainfall than at a higher level on the other side of the ridge.

Where the sides of the hills surrounding a gathering ground are steep, the rainfall will flow off rapidly into the streams, and more particularly where a rocky stratification shows itself on the surface, and there is not much room for absorption and percolation.

On flat tablelands and moorlands, with a great depth of absorbing and undrained material, there may often be heavy rainfalls, which will be detained and evaporated, but from which, being drained, a large amount of water would flow off at a lower level. After a long wet season, however, the absorbing material becomes saturated, and much of the rain will then flow rapidly off the surface at once, but sometimes a much larger quantity will percolate down to an impermeable stratum, from which it will flow off in springs; the proportionate quantities given off under these circumstances may greatly depend on the nature of the materials, some of which will hold water much faster than others, and on the angle of inclination of the substratum over which the water has flowed.

The same observations will bear upon the sands and gravels overlying such formations; for instance, Lias and Oolites. Areas of many square miles under the Lower Greensand overlying the former formation are often, even after very heavy rains, perfectly dry, because the water, at first absorbed and detained, has been afterwards discharged at a lower level by reason of the inclination of the substratum; and frequently this happens at some hundreds of feet lower, where a great deal of water may be found. The inclination of the lower beds will determine on which side of a hill the water will flow out, except such portions as may meet with a large rent or fault, and which may be carried off in another direction.

The aspect of mountains and hill sides, and of the troughs and subsidiary valleys with which they are furrowed; their proximity to the sea and their altitudes; their geological construction and the configuration of such construction; the inclination of the sides and of the geological formations, and whether or not these form basins of absorption; the overlying materials;—all these are important elements as to the amount of rain fallen, the evaporation and absorption, and the discharge of water: it will be seen that great discrepancies frequently must appear to rise between the amount of rainfall and the discharge of water from a given district, until by proper observations such discrepancies are reconciled; to accomplish this satisfactorily often consumes a greater amount of time than may at first sight be imagined; frequently, however, it has to be done.

It will be seen that over an extensive gathering ground with any such characteristics as we have above referred to, numerous gauges to measure the rainfall, and numerous overfalls to gauge the quantities discharged by the streams are often absolutely necessary where we look for anything like close approximations to the quantities of water that may really be obtained.

We may have parallel valleys of greater or less magnitude drained by streams and tributaries, and of which the conformation at the surface and the geological configuration underneath may be such that one valley may, as it were, completely rob the other, both as regards rainfall and discharge of water absorbed; but the extent to which this may occur can only be ascertained by careful gauging, both of streams and rainfall. This fetching of water by one valley from another often takes place for great distances and far beyond the apparently legitimate range of any particular gathering ground.

In the chalk, unless where the sides of the hills are steep, a large proportion of the rainfall is absorbed, and carried down to flint beds, where it is stored in large sheets of water; in this formation, also, water is often fetched from great distances by a flat underlie. The water is hard, though a most agreeable drinking water.

The Silurian formations, the granites and the older rocks generally, as well as volcanic districts, throw off water very rapidly; these and the millstone-grit formation are all favourable for giving fine soft water.

Sandstones and shales form excellent filters, and the water flowing from them is always very pure, and generally of one or two degrees of hardness.

The Old and New Red Sandstone formations have great powers of storing water, as exhibited by the numerous wells formed in these formations.

It often occurs that in gathering grounds, otherwise excellent, there may be portions yielding water of an inferior character, such as that flowing from decomposing peat, or from a tract of land highly manured, or from a metalliferous district; the quantities of water discharged from such districts have generally to be ascertained. Similar observations may have to be made as to quantities of hard and soft waters, and of the purest, flowing from one gathering ground. Such may be required for dye, print, and chemical works; we may have to ascertain the quantities of water discharged by streams appropriated by existing mills or other interests, and also of such waters which it may be desired to substitute for them.

Enough, we suppose, has now been said to explain the importance of careful examination of extensive gathering grounds, not only as regards formation and configuration, but also as regards the position of stream and rain gauges.

Where a number of rain gauges are used it is more than desirable that they should all be of exactly the same diameter; this may be from 6 to 12 inches, at the option of the observer; their being all of one size obviates the necessity of their being more than one graduated measuring glass; and, as this is an important though very simple instrument, we will say a few words about it, because, unless care be taken, it is very likely to get broken.

The area of the rain gauge funnel, multiplied by 252·458, the weight in grains of a cubic inch of distilled water, and the product divided by 437·5, the number of grains in one oz. avoirdupois, gives the weight in ounces of one inch depth of rain over the area of the rain gauge; then the depth of any cylindrical glass, containing such quantity of water and graduated into tenths and hundredths, will give the depth of rain over the area of the gauge. If, for instance, the diameter of the rain gauge is 7 inches, then the area will be 38·4846 inches, and we shall have

$$\frac{38{\cdot}4846 \times 252{\cdot}458}{437{\cdot}5} = 22{\cdot}205.$$

Then any glass containing 22·205 ounces of water, and graduated as above, will give the means of measuring the depth of rain which has fallen on the gauge.

The above calculations are shortened by using the constant 0·577; thus 38·4846 × 0·577 equal to 22·205, and the same for any other area of gauge; then as a general rule we have the square of the diameter of the area of gauge × 0·7854 × 0·577, which gives the weight in ounces of one inch depth of rain over the gauge. The same result will of course be obtained by simply multiplying the square of the diameter by the constant 0·45317.

Where we have any glass of a given diameter, and we wish to find the depth that shall contain a quantity of water equal to 1 inch distributed over the area of the rain gauge. Divide the weight in ounces of such inch of water by the square of the diameter of the glass multiplied by the above constant 0·45317; the quotient will be the depth of the glass, which, divided in tenths and hundredths, gives the graduations required. For instance, let the glass be 4 inches in diameter, and the diameter of the gauge 7 inches as above, then

$$\frac{22{\cdot}205}{4^2 \times {\cdot}45317} = 3{\cdot}06 \text{ inches.}$$

The hydraulic inclination of streams and rivers is found practically by dividing the head of water by the length.

The hydraulic mean depth is the sectional area of water divided by the wetted border or perimeter.

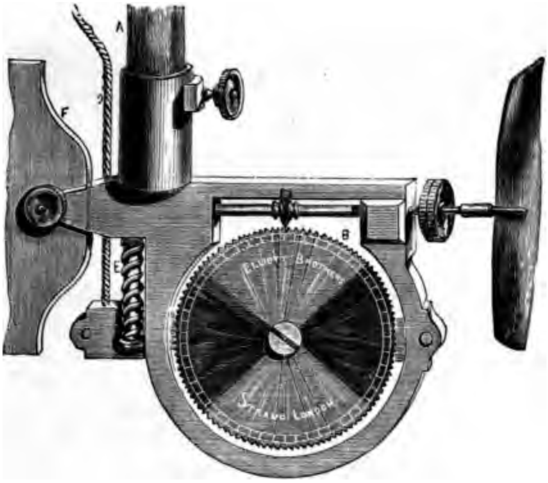
The mean velocity is found approximately by multiplying the maximum velocity, which is at the surface and centre of a current, by the following co-efficients :—

0·81 for small channels
0·835 for large channels, but not irregular rivers.

For crooked channels, with shallow streams over beds of stones and weeds, the above co-efficients may be reduced to 0·7.

The surface velocity of streams may be measured by floats; where we have nothing better at hand, a slice of apple makes a very good float; the velocity with which this flows over a hundred feet of the stream should be ascertained by repeated experiments.

To measure the discharge of rivers by mean velocities, we should have a section across the breadth, and, according to inequalities in the bed, this breadth should be divided into sections, and mean velocities obtained for each of these.



The current meter is a useful instrument for measuring the velocity of streams at any depth of water; we here give a figure of this instrument. A is a rod to sink it to any required depth; C, is a vane or 'fly,' the axle of which carries an endless screw turning a graduated wheel B, which indicates the velocity; F, is a plate which steadies the instrument, and keeps it vertical.

By giving a slight pull to the line D, the instrument is released. The velocity of a stream may be ascertained at any depth, and a suitable average velocity may be taken to ascertain the discharge. The current meter is useful also to ascertain the velocity of under currents.

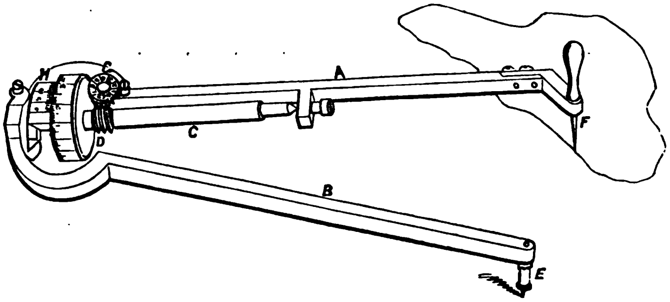
The *constant* for every current meter must be ascertained by experiment.

CHAPTER XII.

OFFICE WORK.

LAND QUANTITIES — PLANIMETER — REDUCING PLANS — PANTAGRAPH — EIDOGRAPH.

ASCERTAINING land quantities from plots, or scaling, as it is termed sometimes, is a most tedious operation, when we have any large quantity to deal with; the method almost always adopted in practice is to reduce the figure to be scaled to some parallelogram, or divide it into triangles. The planimeter of Messrs Elliot, here illustrated, shortens this very tedious operation. E and F are two points at the ends of the moveable arms, A and B; when in use the instrument rests on these two points, and on a third, being that part of the graduated wheel D which is tangent to the paper. G is a graduated disc connected with an endless screw, and H is a vernier to the wheel D.



In the operation of computing with the planimeter, place the point E conveniently on the paper, so that the tracer F may be in a position to be run over the greatest possible portion of the periphery of the figure to be measured; then read off the instrument; trace the contour a second time and again read off; subtract the first reading from the second, and multiply the remainder by 10, which gives the reading in square inches, with two places of decimals. Let the first reading of the disc G be 2, that of D equal to 80, but with the vernier reading instead of 80 let it be 805; then the reading of the instrument at starting is to be set down as 2·805; let the second reading be 7·553; this, minus the first, equal to 4·748, which multiplied by 10 equals 47·48 as the contents in square inches.

In tracing the periphery, observe whether the disc G performs an entire revolution, for in that case 10 must be added to the unit in the last reading. If, for example, the second reading above had been 7·553 plus an entire circuit, then we should have had 7·553 plus 10 equal to 17·553, from which subtracting 2·805 and multiplying the remainder by 10, we get 147·48. If the periphery is too long for the instrument to trace at once, the figure may be divided into two or three. The instrument is constructed to give areas in other denominations than square inches; but this is a very convenient one for the English Ordnance Map of one inch to the mile, in which the above computation would give 147½ square miles.

Let us now suppose that we are computing from a plan with a scale of 5 chains to the inch; 5 chains square is equal to 250,000 square links; from this we obtain the constant by which to multiply the number of square inches found with the planimeter to reduce the area to square links.

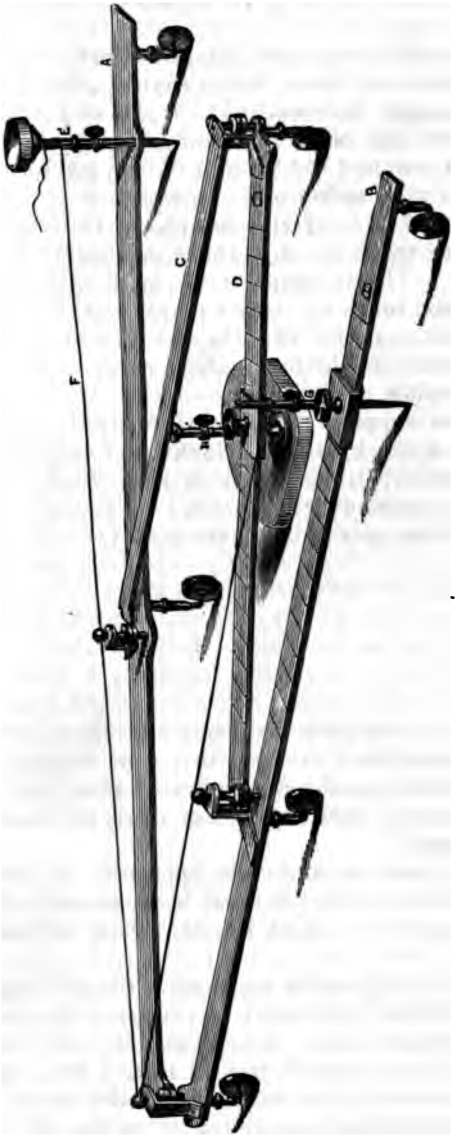
Then for a	1	chain scale	we shall have	100
,,	2	,,	,,	400
,,	3	,,	,,	900
,,	4	,,	,,	1,600
,,	5	,,	,,	2,500
,,	6	,,	,,	3,600

as constants by which to multiply the square inches found with the planimeter, to reduce them to square links, which will be the more easily remembered, from the multipliers being the square of the number of chains to one inch, with two zeros added.

Reducing plans is a simple operation, which, however, requires care and some practice, because the reduced plans are often required at short notice. The work of reducing is often done with proportional compasses, but we prefer having this done by squares; that is to say, the plan to be reduced is divided into a certain number of squares, each perhaps ten chains wide. The paper on which the reduced plan is to be drawn is then divided into the same number of squares, but adopting the proper reduced scale for the width of the smaller squares.

When the plan to be reduced is of any great extent, a large amount of labour is saved by making use of the pantagraph or eidograph, represented in the following figures.

The pantagraph consists of four flat rulers, made either of wood or brass; the two outside ones are generally from 15 to 24 inches long, and the others about half that length; the longer ones are united together by a pivot, about which they turn, and the two smaller rulers are similarly attached



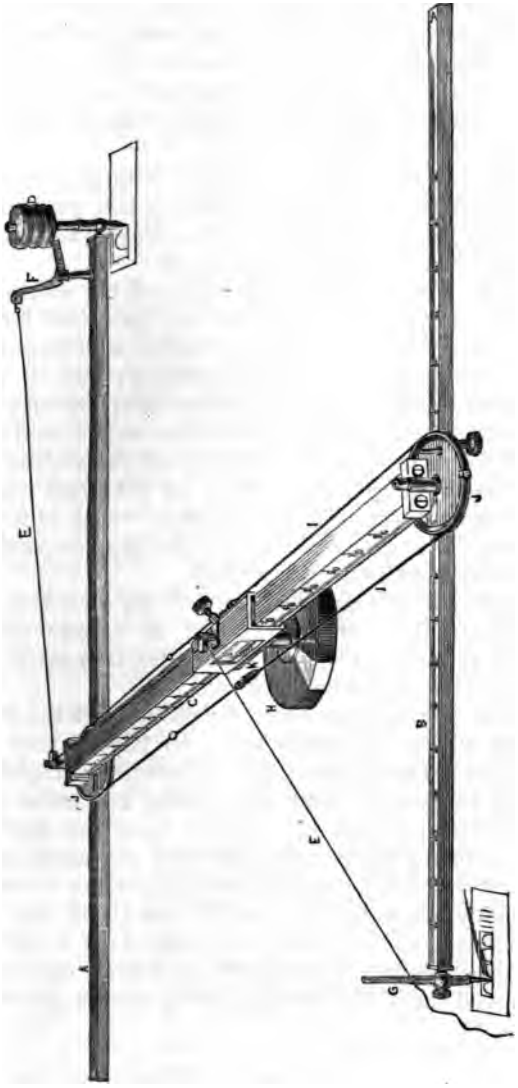
to each other, and to the longer rulers. A sliding box is placed on each of the arms, A B and C D, which may be fixed by a clamp-screw at any part of the ruler; these slides carry a tube, to contain either a blunt tracing point, a pencil or pen, or the fulcrum B, which is a heavy weight of lead, having a point on the under side, to pierce the drawing board and remain immovable in its proper position, it being the centre upon which the whole instrument turns. Several ivory castors support the surface of the machine parallel to the paper, as well as facilitate its motions.

Two of the arms are graduated and marked with the ratios, $\frac{1}{2}$, $\frac{1}{3}$, &c., so that when a copy of a plan is required to be made in any of these proportions, it is only requisite to fix at the required ratio the slides carrying the fulcrum, B, and the tube, with a pencil or pen, and the instrument will be ready for operation. Thus, suppose it were required to make a copy of a plan exactly one half the size of the original; the slide carrying the pencil, and that working on the fulcrum B, are each fixed by their respective clamp-screws at the divisions marked $\frac{1}{2}$; the original plan is placed under the tracing point, and exactly parallel to it is placed a sheet of paper under the pencil, the pentagraph being spread out so as to give room for the tracing points to be passed over every line on the plan; whilst the pencil is making corresponding marks on the copy, which it is evident will be equal to one half the size of the original. A fine string is attached to the pencil-holder, and passed round by E to G, the tracing point, the pulling at which raises the pencil a small quantity above the paper, to prevent false or improper marks upon the copy. It should also be remarked, that the cup represented on the top of the pencil-holder is intended to receive a weight, to keep the pencil down upon the paper, or when a stronger mark is required.

When the instrument is set for work, the tracing point, the pencil and the fulcrum, must in all cases be in a straight line, which may be proved by stretching a fine string over them.

When it is required to make an enlarged copy of a plan, the setting of the instrument is precisely the same as above stated, only the tracing point and pencil must change places, the original being placed under D, and the copy under C. But when a copy is to be made of the same size as the original, the fulcrum must be placed in the middle at D, and the pencil at B, under which will be the copy, whilst the original must be placed under the tracing point at C.

The eidograph, which is represented in the accompanying engraving, is a far superior instrument to the pantagraph, being more exact in its work, and not so limited as regards ratio of reduction.



The point of support when the instrument is at work is a heavy weight shown at H, from the under side of which three or four projecting needle points fix the instrument firmly to the drawing paper. Springing from this weight is a short standard or fulcrum, attached to a sliding-box, K, in which slides the centre beam, C, and to any part of which it may be clamped by means of a clamping screw.

At the end of the central beam are two pulley wheels, J J, the centre pins of which revolve in sockets at the ends of the beam. Two steel bands, I I, attached to the pulley wheels, give them an exactly simultaneous motion, and these bands have a screw adjustment, K, by means of which they may be tightened.

The arms A and B are made to slide through boxes under the pulley wheels, and may be clamped at any proportion of their lengths in the same manner as the central beam, C, may be made to slide and clamp in the box K.

The arm B carries a tracing point, G, and the arm A carries a pencil point, D. The pencil holder may be raised by means of a cranked lever, F, attached to a cord, E, which passes over the centre beam, and thence to the tracing point, G.

The two arms and the beam are divided into 200 equal parts, which are figured 100 each way from the centre, and may be read to 1000th by means of the verniers on the sliding-boxes.

There is a loose weight which may be attached when the instrument has been set, and the object of which is to steady it when there is a great difference in the proportions to which the instrument is being worked.

It will be observed that the pulley wheels give the easiest possible motion; these wheels should be of exactly equal diameter, and as they are turned in a lathe, this equality may be obtained to the greatest perfection.

To bring the instrument into adjustment, let the verniers be set to zero, which will bring them to the centres of the arms and of the central beam; place the arms at right angles to the beam, as near as you may guess, and make a mark with the tracer and pencil point, and turn the instrument round so as to bring the pencil point into the mark made by the tracer; by doing this you will make the tracer move to the mark previously made by the pencil, exactly if the instrument is in adjustment; if otherwise, the error in difference should be bisected, and the adjusting screws on the band should be moved until the tracing-point comes exactly into the bisection.

CHAPTER XIII.

ELEMENTARY PLAN DRAWING.

MANAGEMENT OF DRAWING PAPER; MOUNTED PAPER—STRAINING DRAWING PAPER—STRAIGHT EDGES—SCALES—DRAWING PENS AND INK—COLOURING PLANS.

There are two kinds of drawing paper used in the preparation of plans—mounted and unmounted; the mounted paper may be purchased of almost any length, sheet after sheet of various widths being pasted on linen, or on what is called 'union cloth;' and it is generally on this paper that railway plans are prepared. The paper, however, is generally of an inferior quality, and rather thin; for plans of a superior quality, where there is much drawing or colouring, it is better to order a few sheets of the best drawing paper to be mounted at some of the large stationery establishments, such as Spottiswoode's, Waterlow's, Vacher's, or Metchim's, all in Parliament Street; we mention these, because they have great facilities for executing an order at once; the dimensions of the paper used for this purpose are generally imperial, 30″ × 22″; atlas, 34″ × 26″; double elephant, 40″ × 27″; antiquarian, 53″ × 31″.

Sometimes, however, we are placed in situations where we are obliged to mount our paper ourselves; this often occurs abroad. To mount paper on linen or calico, the cloth should be laid upon a large smooth board of sufficient width and length: the cloth should be damped, and the edges should be tacked down to the board, the tacks being pretty close together, and care should be taken not to pull upon the edges of the cloth; it should lay on the board just flat and smooth. Or we may lay a long flat rule about half an inch from the edges of the cloth, and glue them down to the board, laying on the glue hot and rather thick, with a flat brush about a quarter of an inch wide; it is not difficult to do, but requires a little care not to strain the cloth; if it has been damped and laid flat, it will lay smoothly on the board.

Having laid down the cloth, the next operation is to lay on strong paste, with a large soft brush; in doing this, do not pull at the cloth with the brush, but work the paste well in;

this will not only ensure a better contact with the paper, but will also prevent the cloth from shrinking.

The edges of the sheet of paper should be cut very straight, and if the paper is thick, the edge of the paper at the back may be thinned down with glass paper; the sheets of paper may now be laid down on the cloth, the sheets overlapping each other by about one-third of an inch; if the paper is large, it will take two persons to lay each sheet, and they must take care to lay the paper flat without pulling at the sheets. If the paper is thick, it is well to let it lay a few minutes after the paste is laid on, the sheets will then expand and will dry much smoother on the cloth; if the paper has not been well wetted, it will be apt to rise in bladders here and there over the cloth.

This done, the mounted paper should not be interfered with for a day at least, even in a warm climate; when dry, it should be cut off the board, but before it is used, it should if possible have a good ventilating, and be exposed to the sun, first on one side and then on the other. Fresh mounted paper is apt to contract very much. The cloth should be at least a couple of inches wider than the paper.

STRAINING DRAWING PAPER.

Straining a sheet of drawing paper on a drawing board appears one of the most simple things imaginable: but a little experience shows that it is not quite so easy as first thought. The drawing board should be clean and perfectly smooth, and when we have to produce a plan with more care than usual, it is well to examine the sheet held up to the light in order to see that it has no flaws. It is well to cut the edges of the paper straight and smooth, with the help of a steel straight-edge, and pretty square. The best side of the paper is generally that on which we can read the water-mark in the corner, and this side should be kept for drawing on; the other side should be wetted with a sponge and clean water. We always begin wetting the sheet well at the centre at first, and gradually damping *towards* the edges, but we always leave about an inch at each edge untouched. When sufficiently damped, the paper will begin to bag, and this should be pretty equally all over the sheet, but perhaps a little more in the centre. As soon as the gloss arising from the damping with the sponge has passed off, the paper is ready to be strained.

We now require a long flat wooden ruler, a stout piece of glue, flat and straight, and a little boiling water.

We may now turn the paper over on the drawing-board, that is, with the wetted side downwards; do this quietly, without straining the paper, which on being turned over should be laid with its edges parallel to those of the drawing-board; if they do not come so at first, the paper should be quietly lifted bodily off, and then laid down so that the paper shall lay parallel with the board.

The flat ruler should now be laid on the paper at about half an inch from either of the *longest sides,* and be gently pressed down thereon, so as to hold it firm, but not so as though you wanted to press the wood into the paper; you may now dip one end of the glue into the boiling water, half an inch deep or so, so that it may be partly dissolved.

Beginning at the middle of the edge of the paper, pass the moistened glue once or twice along the turned-up edge of paper towards one of the ends, the ruler being of course held steady; then pass the glue again moistened from the middle of the edge towards the other end.

You may now put down the glue and take up an ivory handled knife, or the handle of a stiff paper-knife, or something of the kind, and pass it firmly along the glued border laid flat to the board, and still working from the centre towards either end; the rule should not be moved until this is done. If sufficient glue has been applied to the paper, not too wet and not too thickly, the edge of the paper will now adhere flat to the board.

We may now move the ruler to the opposite longer, but not adjacent side, and serve it in the same manner; working from the *opposite* sides makes the pull on the paper when drying square with it; it would otherwise be oblique or askew. Having thus laid down the longer opposite sides we take to the shorter ones.

We have given the above simple instructions as for the large sized paper, double elephant or antiquarian, for instance; and having laid down some hundreds of sheets, we know the suggestions are safe, and that by these means a large-sized sheet of paper may be laid down in a few minutes, to lay as tight as a drum and as smooth as water.

STRAIGHT-EDGES.

Unless we use the T square, probably a straight is the first instrument we use on sheets of paper, to draw long straight lines. Straight-edges are generally made of steel, and are generally now what they are professedly sold for, that is, *straight.* When there is any doubt about it, one way to test is to lay it on a flat sheet of paper, and to draw a long straight line along one edge; then turn it end for end, and lay it on the line, and see if it coincides; then turn over the other side, and try it that way on the same line, and again end for end. Repeat the same operations by sliding it along the line, three-quarters and half-ways. If the line and the edge coincide throughout these trials, there is not much to fear. It is just possible, however, that the straight-edge may bulge inwardly or outwardly, on both sides and equally from the centre; to test this, we may draw the straight-edge about half an inch from the line and load it; we may then stretch a fine black silk thread as tightly as it will bear, from one end to the other of the line we have drawn, and if the two coincide, it will be another favourable test.

Another way to try them is to take two straight-edges, and rest them endways on a table, and bring two edges close together; if any light can be perceived between, there is a defect in one of them at least; they may then be turned end for end, and tried in the same way; and then the other side of one of these may be applied in the same manner. To test to any purpose in this manner, it is necessary that they should stand quite upright; or one may be laid flat on edge and another laid upon it, and we may again try and see if the light appears between the edges. To try a straight-edge in this way, one of them in fact should be straight to our knowledge, and altogether we believe that the first method of testing we have described is as good as any if properly applied.

In drawing a straight line along a straight-edge, as for the base line of a survey or for a datum line, we should take care to have a really fine, sharp-pointed pencil; this should be held vertically, as the line is gently drawn with the side of the pencil point close along the straight-edge, and without any wavering as the hand moves along from end to end of the straight-edge.

When with a straight-edge perhaps only five feet long, we have to draw a line that is to be twenty feet in length, more or less, some precautions are necessary. First, draw in a line, from end to end of the straight-edge, and turn the edge over to try the line with the other side, then draw the straight-edge half along the line and produce it; repeat this; then test the whole with the silk thread, which will be a good check, provided the paper lays flat. We may in this manner draw a straight line of considerable length; but this again is a simple operation, which sometimes requires considerable care. In doing this for a datum line, which will not be very far from the lower edge of the paper, we should, after determining the distance of one end of the line from the edge, say three inches, lay off this distance from the edge of the paper at about every foot in length. This will serve for the general direction of the line, and prevent our running the risk of drawing the line much too high up one side of the paper; we refer here to very long lines.

SCALES.

Scales are measures with which we lay off the lengths of lines, or measure them on paper. They are made of ivory or boxwood, the first being certainly the neatest, and also the best where the divisions are small, say sixty to the inch. We have lately tried some made of ebonite, on which the divisions are shown in white, on black of course, instead of black on white or light yellow. We have every reason to be satisfied with them, as we find the divisions, as might be expected, read very much clearer than on the ivory or boxwood; this is a very great comfort, particularly for working at night or on dull days.

The ordinary divisions on scales are 1, 2, 3, 4, 5, 6, 8, 10, main divisions to the inch, and these are, for chain scales, termed 1, 2, 3, 4, &c. chains to the inch; these divisions are all marked in numerals, which read 1, 2, 3, 4, &c. chains to the inch; and the chain may be 100 feet or 66 feet; we have referred to this in our first chapter. But these main divisions are subdivided into ten, and each of these reads 10 feet or 10 links of Gunter's chain; this at once shows the necessity of writing in on a plan, from the first day of plotting, the scale used, and whether it is in feet or links, the latter being a measure, as an engineering one, which probably we shall be rid of some of these days.

These same scales, however, may be made to read in another way, and that is 1, 2, 3, 4, 6, 8, 10 feet to the inch, in which case each *subdivision* will show the tenth part of a foot.

And again the same scales may be used for drawing in work, at 10, 20, 30, 40, 50, 60, 80, and 100 feet to the inch, in which case each *subdivision* will read one foot.

In laying off a length along a line with a scale, it is always well to check, by applying the scale, so that it shall read backwards. We advise the beginner always to do this; it is a simple check, and may prevent his spoiling a week's, or even a month's, work. The writer is not a beginner, but it is a precaution which he always adopts.

DRAWING PENS AND INK.

Lines are drawn first in pencil, and then generally in Indian ink with drawing pens; of these the draughtsman should have three or four, of different sizes, and of different thickness of nib, to draw different thickness of lines. The best drawing pens are made jointed, so that by unscrewing the nibs, the inside of a pen may be wiped clean. In drawing lines with a drawing pen, it should always be held vertical. A very fair way to begin learning how to use a drawing pen is to draw one hundred *parallel* lines about 18 inches or 2 feet long, in the breadth of an inch, and so that when seen at a little distance, there should only be one shade of grey; if the work looks darker in some places than in others, it is because the lines are there too thick.

The Indian ink used in drawing should be tolerably thick, but this can only be understood by a little experience; it is, however, soon learnt; the lines should be dark, however fine, and not pale. When grinding up Indian ink, do not be afraid of having a little too much, and when at work, always keep your ink covered with a saucer, it prevents its becoming dusty, and getting thick and muddy. Keep your paper clean; do not touch it with the hands more than you can help, as the hand makes the paper greasy, more particularly in hot weather, and you will never get clean sharp lines when once the paper has acquired this defect. Do not use the Indian rubber more than is absolutely necessary, as this makes the paper 'fluffy.' If after working some time you find the ink does not run freely from the pen, you may amend this by passing a slip of paper between the nibs.

In drawing with pen and rule, keep your pen upright, and sufficiently against the edge of the rule as to be guided by it, but not pressing against the edge, as this will produce wire-drawn lines, that is, of unequal thickness, and with a wabbling appearance. Begin inking in over your pencil lines by working from the top of the paper towards the bottom; this will prevent your running the risk of smearing your work.

Keep your pens and drawing instruments so that they will not get knocked about; it is easier to spoil a drawing pen than it is to mend it; keep your stick of Indian ink so that it will not get 'smudgy' or greasy.

In plan drawing, the lines of buildings are drawn in with the drawing pen and rule; lines of fences, roads, rivers, &c. are drawn in with the drawing pen by hand over the pencil line, that is without the help of the rule; the banks of little brooks, where neatness is required, are best drawn in with the lithographic steel crow-quill.

COLOURING PLANS.

We wish now to say a few words about colouring plans. It is true that this in no way affects the accuracy of a plan, but it is equally true also that it looks well, that it pleases, and shows that the draughtsman has taken pains with his work. We have known a case where a wealthy landowner stopped the survey of an extensive estate which he had ordered, simply because the plan looked ugly.

The colours used for plan drawing are principally the following: Indian yellow, gamboge, yellow ochre, burnt sienna, cobalt blue, and Prussian blue, carmine or lake, neutral tint or Payne's grey, and olive green, Hooker's green, and one or two more.

These tints of green are very convenient, particularly when large areas are to be coloured in one tint. With cobalt blue or Prussian blue mixed with either Indian yellow, gamboge, or burnt sienna, we may produce almost any number of tints of green, but if any of these are thrown away, and again wanted afterwards, it is very difficult to reproduce the tints exactly.

By mixing any blue, red, and yellow, in different proportions, we may produce a great number of neutral tints, but the same observation holds with regard to them as with regard to the greens. We prefer mixing those colours where we want to produce reliefs, as, for instance, in foliage or cliffs.

Pasture and meadow lands are coloured green, using a different tint for each, and another for water meadows, or irrigated lands, introducing a little cobalt or Indian blue, according to whichever produces the most agreeable tint; these little matters can only be ascertained by trials and laying one tint alongside of another.

Arable lands are shown either with yellow ochre or burnt sienna, the furrows being shown by parallel lines, every third of which should be stouter than the other two; these lines should not be drawn by rule, but by hand.

Water in rivers, lakes, ponds, or the sea, are shown in cobalt, softened off with water at the edge, and then picked out with Prussian blue along the shore lines by means of a fine pointed brush. These two colours are all that are required to produce the best effects for water, but nothing but practice and a little taste will enable the student draughtsman to acquire a correct way of handling the subject.

Some fair samples of foliage are shown in some of the plates accompanying this volume, but they are in black and white. Where trees are to be produced in colour, one of the first things to do after they have been drawn in pencil is to get in the shadows in grey or cobalt, using the same colour for the first shadows in the foliage; the lights may then receive a touch or two of gamboge, or burnt sienna, and then the greens may be got in; finally, we may pick out here and there with Prussian blue; of course different tints are to be used for trees that differ most in colour, and if the point of the brush is handled nicely, some of the characteristics of different foliage may be obtained.

To produce the effect of marsh land, two brushes should be used on one stick, the one with green and the other with blue; and these should be used so that at the edges one colour should run gently into the other, but without producing a patch.

Roads are coloured in burnt sienna, shaded with the same, and the shadow softened off towards the centre of the road.

A great deal of effect may be displayed in some of the cliffs; oolites, and such like may be shown with yellow ochre picked out with burnt sienna, and a little neutral tint for shadows.

The red sandstones may be got out best with Indian red and cobalt.

Gravels and the lower greensand may be shown with burnt sienna and a little neutral tint, and chalk cliffs may be represented by white, shaded with a neutral tint, which may be made up of cobalt, lake and gamboge; mixed in different proportions, these will produce any variety of neutral tint.

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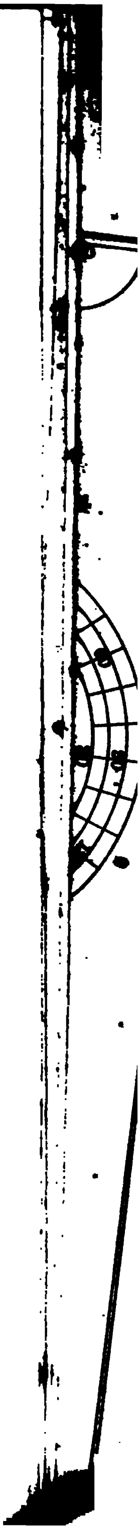

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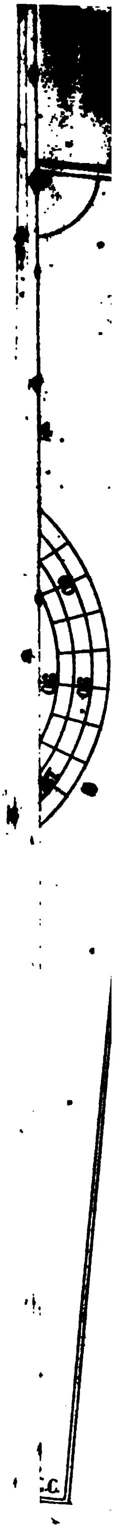

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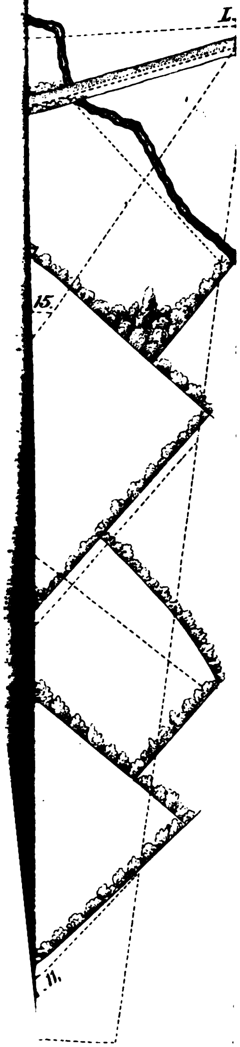

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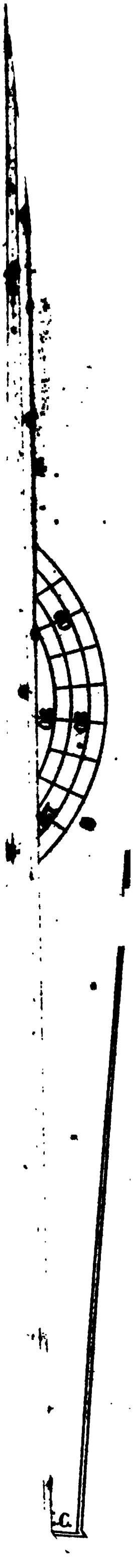

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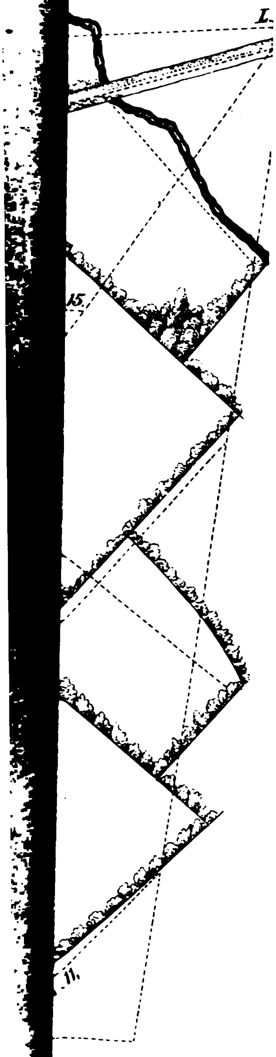

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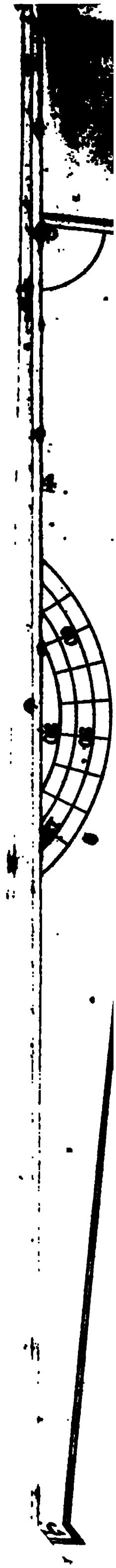

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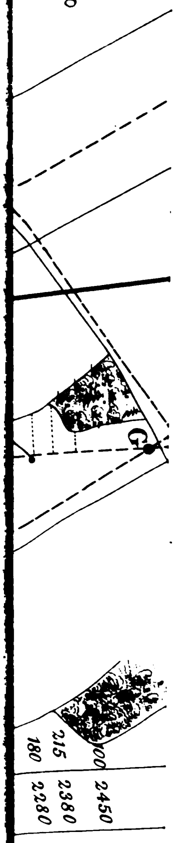

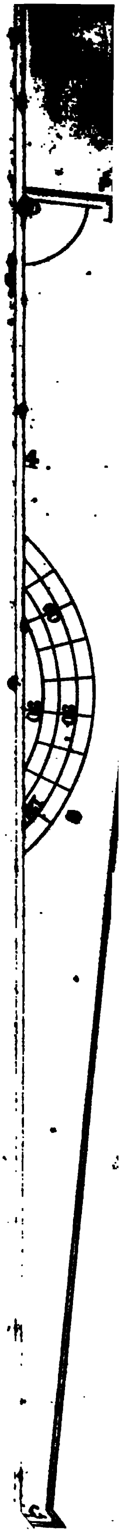

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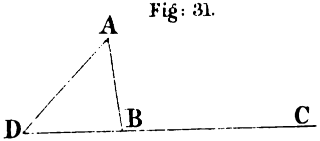

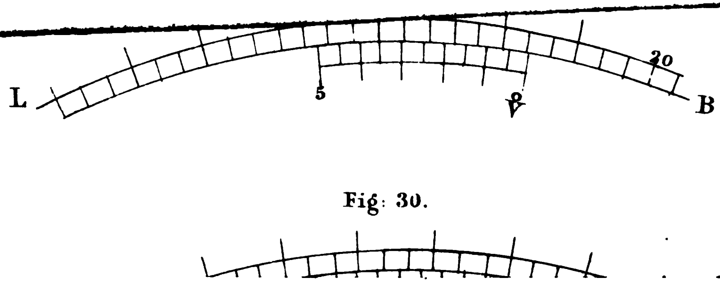

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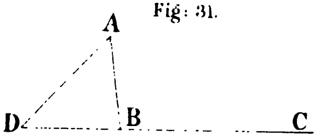

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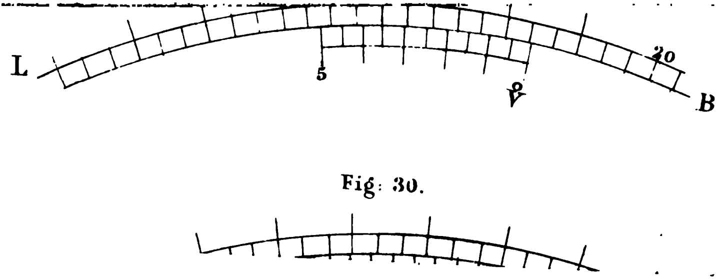

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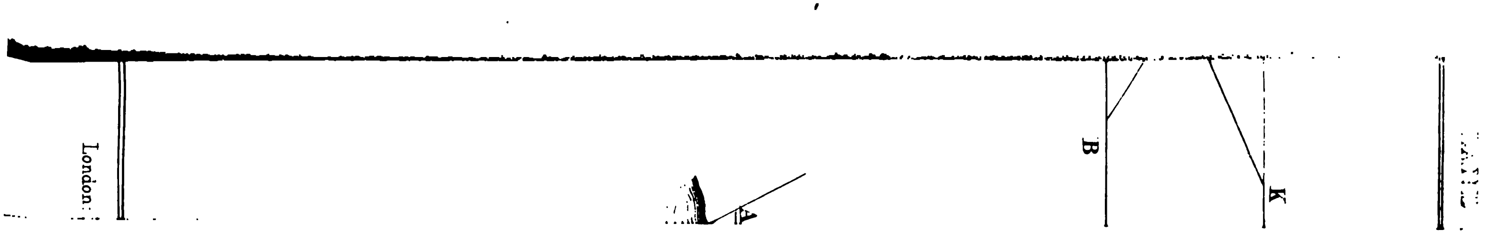

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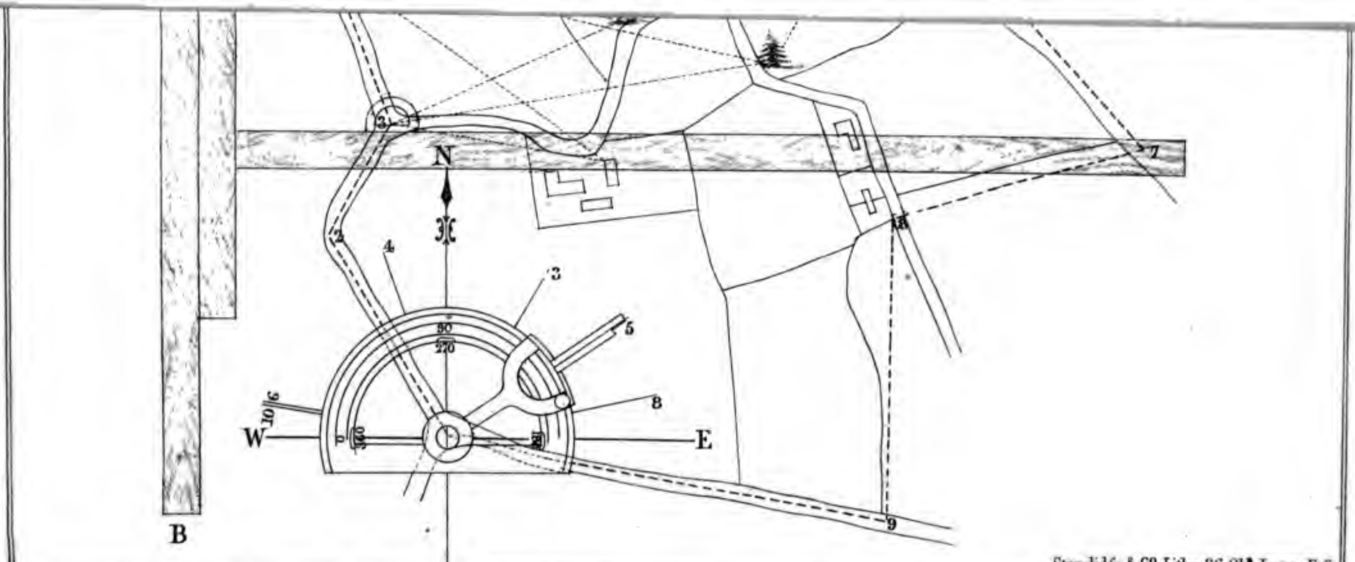

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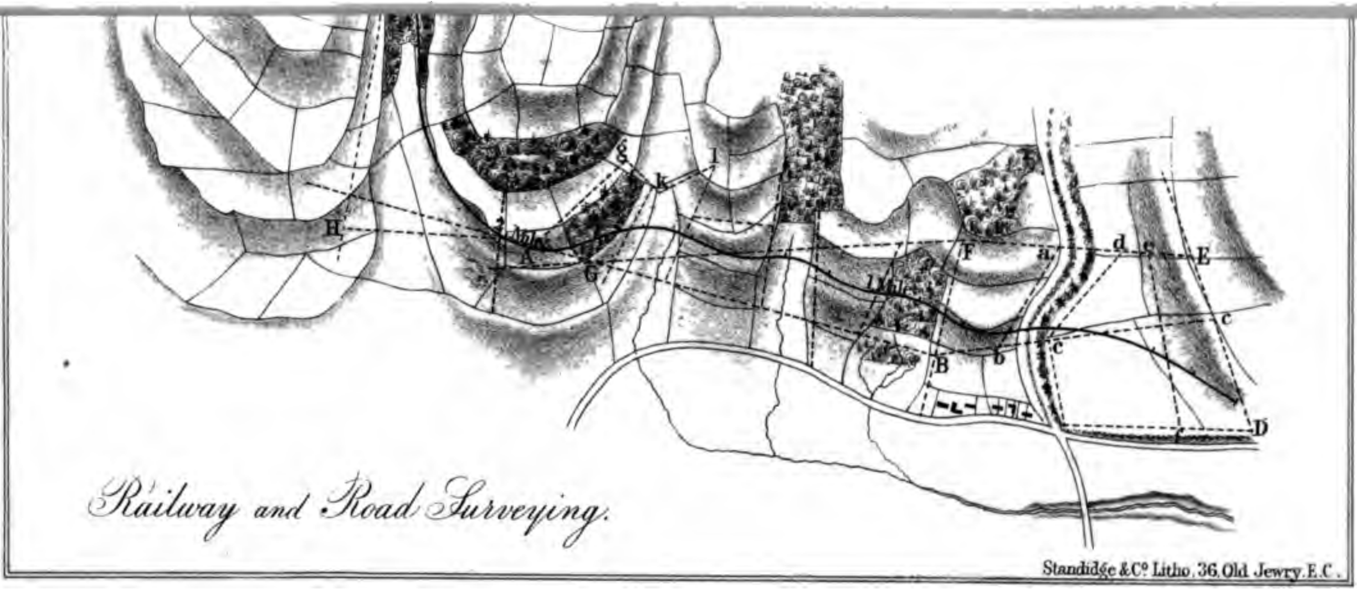

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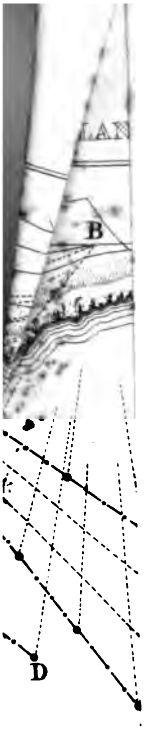

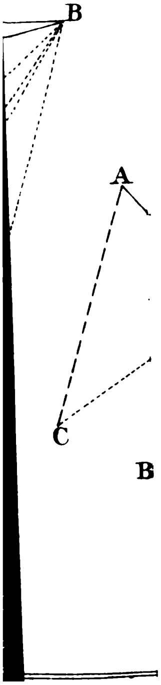

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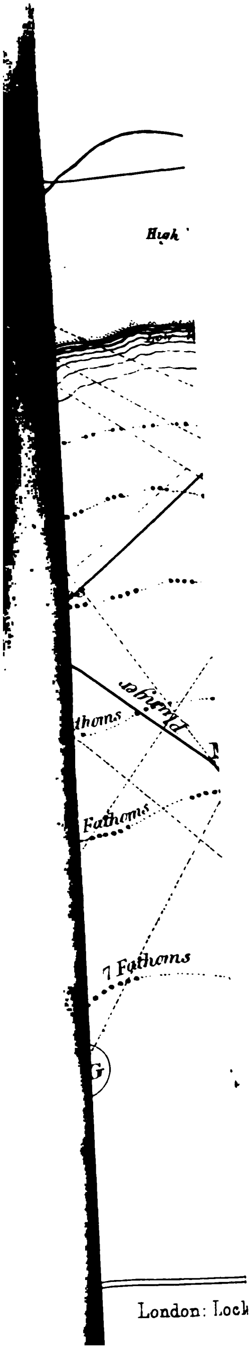

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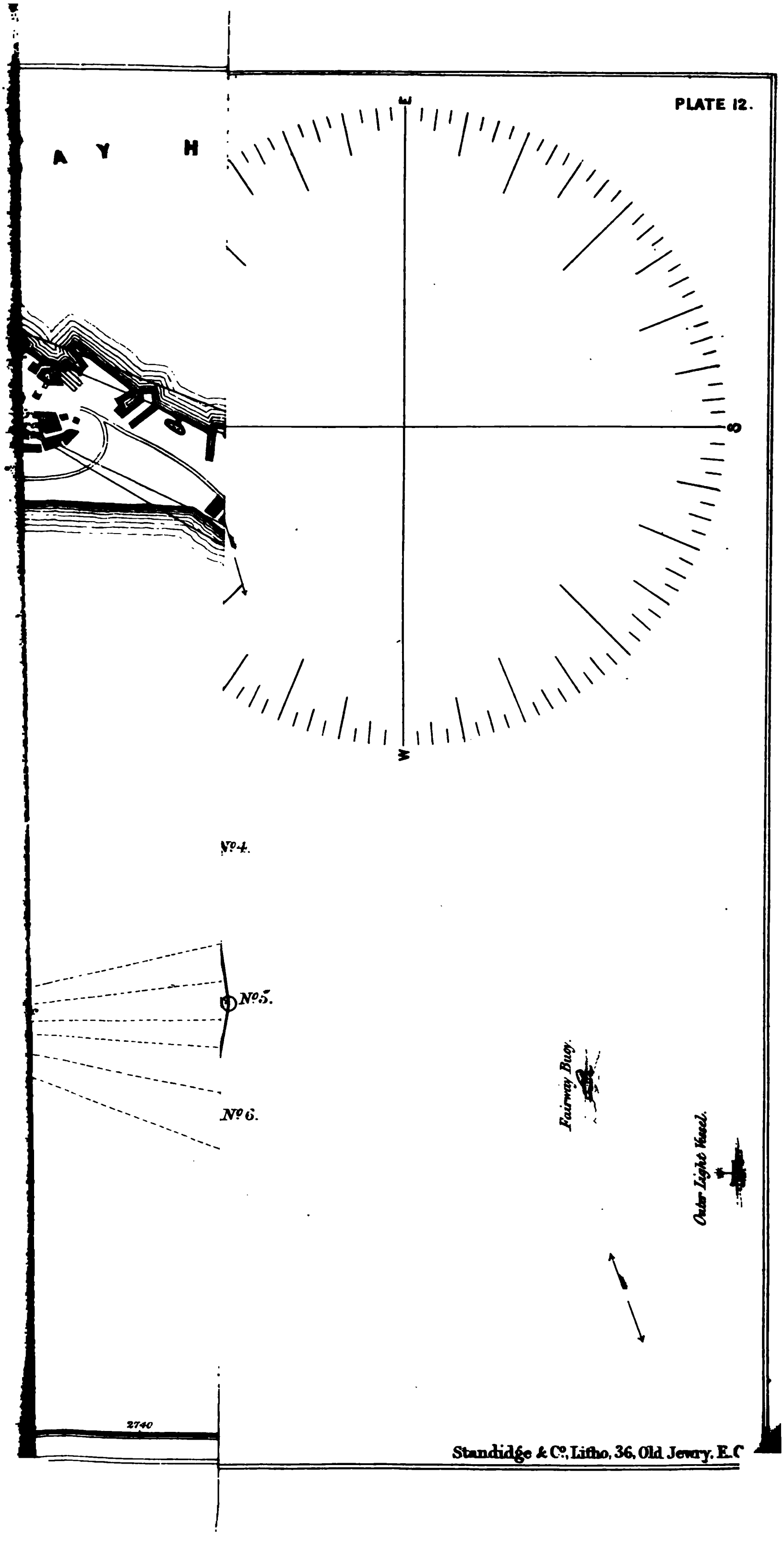

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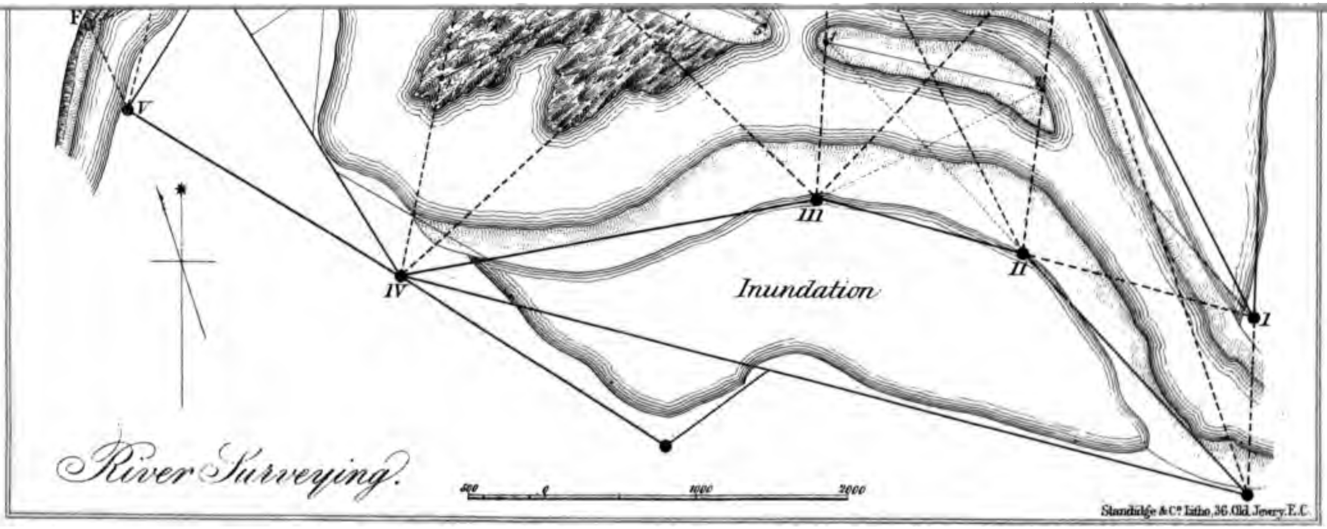
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